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Performance of Fire Protective Coatings Subjected to DC-ARM Wartime Scenario Fires Aboard Ex-USS *Shadwell*

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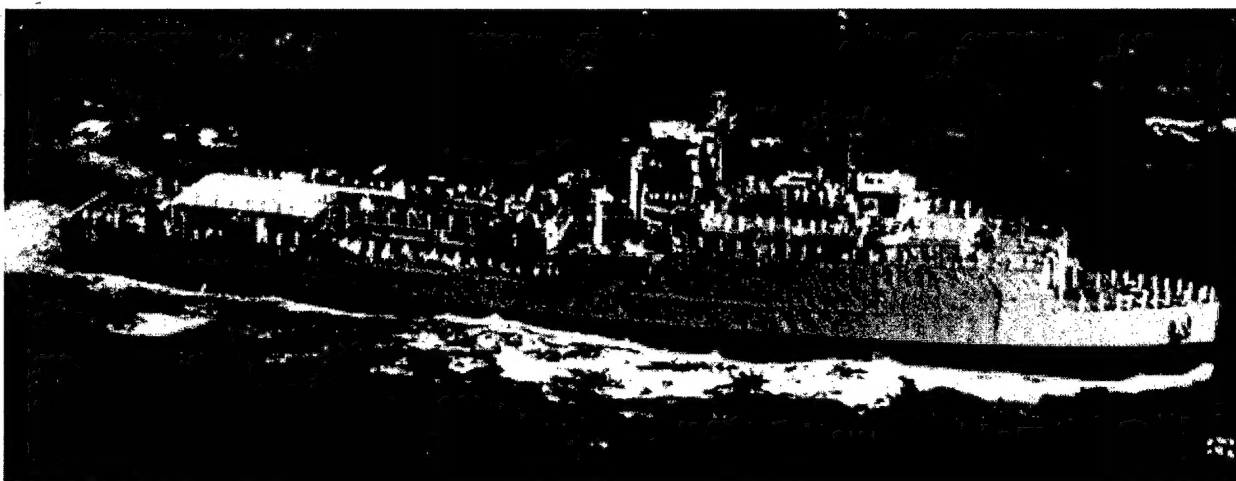
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14. ABSTRACT

The subject test coatings were applied in a range of thickness in excess of Navy paint application. Radiant flux from the wood crib fire was insufficient to trigger any intumescent response in the C. B. Environmental products FB-1 and FB-520. Direct flame impingement from the heptane pool fire did not provide an insult sufficient to activate any large-scale, intumescent response from the C. B. Environmental product FB-2. The C. B. Environmental coatings FB-1, FB-2, and FB-520 may provide some thermal resistance to conductive heat transfer at an application thickness of 60 to 80 mils.

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CONTENTS

Nomenclature:

APDA	- Adjacent to Primary Damage Area
c	- specific heat, for solids $c_v = c_p = c$
h	- convective heat transfer coefficient
k	- material thermal conductivity
q''	- heat flux (Btu/ft^2/hour)
C	- Calorimeter, total heat flux transducer
PDA	- Primary Damage Area
R	- radiometer, radiant heat flux transducer
T_c	- thermocouple
T_s	- temperature of the exposed surface
T_∞	- temperature of the fluid at some distance from a surface
α	- material thermal diffusivity, $\alpha = \dfrac{k}{\rho c}$
$\dfrac{\partial}{\partial t}$	- partial derivative with respect to time
∇^2	- Laplacian operator, $\dfrac{\partial^2}{\partial x^2} + \dfrac{\partial^2}{\partial y^2} + \dfrac{\partial^2}{\partial z^2}$
σ	- Stefan-Boltzmann constant
ρ	- material density

PERFORMANCE OF FIRE PROTECTIVE COATINGS SUBJECTED TO DC-ARM WARTIME SCENARIO FIRES ABOARD EX-USS *SHADWELL*

1. Background:

A fundamental goal of shipboard firefighting is to find the fire quickly, attack it efficiently and confine it to the area of origin (Ref. (1)). In order to satisfy this principal, fire spread must be controlled.

Based on our current knowledge of fire dynamics we know that vertical spread of fire could occur within 10 minutes of the fire compartment reaching the flashover stage. Horizontal spread of fire can occur within 20 minutes of the fire compartment reaching the flashover stage (Ref. (2) – (5)). Control of heat transfer from the fire compartment to the surrounding compartments has been proven to be critical in the control of fire spread.

The subject coatings were provided to NRL, gratis, and applied aboard ex-*Shadwell* by the manufacturers. The coatings and required application labor were provided to a level sufficient for one test only. The test was performed in conjunction with the FY00 DC-ARM demonstration on a not to interfere basis using computer and instrumentation resources not already designated for the DC-ARM program. The discussion that follows will describe what the authors believe happened based on theory, experience and the available data. Further testing and data would be required to reach any conclusion that would either include or preclude use of the subject coatings aboard Navy ships.

2. Theory:

The three modes of heat transfer are conduction, convection and radiation. Conduction is the mechanism that allows thermal energy to transfer from one discreet molecule to another being in direct contact. Conduction is the means by which your hand is burned when grasping a hot cast iron frying pan without benefit of a potholder. Use of the potholder will not defeat the heat conduction process, it merely slows it down. The potholder acts as a layer of insulation. Its presence serves two purposes. It increases thermal resistance to transfer of heat between the hot metal and your hand and it reduces the rate at which your hand can be exposed to that heat. The rate at which heat is conducted through a material is a function of material thermophysical properties, magnitude of the heat source, magnitude of any temperature gradient within the material and the time rate of change of mean material temperature.

The convective mode of heat transfer is the result of fluid movement over the surface of a heated material. This is the method by which your skin cools when exposed to air coming from an air conditioning damper or a fan. The rate at which heat is convected from a surface is a direct function of surface geometry, fluid motion, fluid thermodynamic properties and temperature differential between the heated surface and its surroundings.

The final mode of heat transfer is radiation. This is the mechanism by which our atmosphere is heated by the sun. Radiation can occur in a vacuum and requires no intervening medium. The rate at which heat is radiated from a surface is a function of surface thermophysical properties and the existing temperature differential between that surface and it's surroundings.

Considering non-steady state conditions for a homogeneous isotropic solid the modes of heat transfer can be described as,:

$$q''_{Conduction} = \nabla^2 T = \frac{1}{\alpha} \frac{\partial T}{\partial t}$$

(1)

$$q''_{Convection} = h \, (T_S - T_\infty)$$

(2)

$$q''_{Radiation} = \sigma \, \varepsilon \, (T_S^4 - T_\infty^4)$$

(3)

The total heat flux emitted by a surface can be defined as.

$$q''_{Total} = q''_{Radiation} + q''_{Convection}$$

(4)

3. Experimental Set-up:

The test coatings were applied by coating manufacturers representatives to a newly installed bulkhead at frame18, second deck, aboard the Advanced Fire Research Laboratory, ex-USS SHADWELL (Ref. (6)). The bulkhead was constructed of seven individual, 4'x 8'x ¼" sheets of carbon steel welded to a steel frame. A joiner door was installed into panel #4 to allow personnel passage through the bulkhead. Location of the test coatings, manufacturer's product code identity and the thickness of coating application are shown in Figure. 1. Type K thermocouples were placed against the surface of selected panels, on both fire and non-fire side of the bulkhead, at known locations and coating thickness (Table 1). These thermocouples recorded coating surface temperatures over time. The coatings were applied aft bulkhead construction was completed. Application depth was determined by manufacturer representatives.

Type K thermocouples were also placed throughout boundary compartments to measure air temperatures. Additional thermocouples were placed in a pile of ALPHA materials and in both test fires to monitor ignition and progress of the fires.

Radiometers and calorimeters were aimed at regions of known coating thickness, from the non-fire side, to measure radiant and total heat flux. An optical camera was placed in a viewing port on the starboard side, aft of the test bulkhead to give visual reference to both the ALPHA and BRAVO fires. An additional optical camera was placed on the starboard side, forward of the test bulkhead, to view any sympathetic ignition of the ALPHA materials placed against panel #6.

Forward side of Test Bulkhead

0			60	Untreated	40	
	60	DUCT		Steel	60 45	DI
			50	DOOR		
5	Untreated	40			50	Ur
	Steel					Ste
50		50			65 70	
			65			
0		45			50	

-COAT   TEMP-COAT   TEMP-COAT

After side of Test Bulkhead

80	100 95		50	60	60	
5	95	DUCT		DOOR	50 60	DI
		110 70		40		
5	90		40		60	80
		110				
60	80 80	110 70			60 60	80
		80				

-1   FB-520   FB-520   FB-1   FB-2   FB

Figure 1. Schematic of Test Bulkhead Showing Coating Application
Panels Numbered 1-7 From Left to Right

Table 1. Instrumentation/Coating Type Measurement Location and Coating Thickness

Panel #	Side	Channel #	Lateral Position (Inches)	Vertical Position (inches)	Type of Instrumentation	Coating Name	Coating Thickness (mils)
1	Forward	19A,56B,57B	32.5	23.5	T_c, R,C	Temp-Coat	40
1	Aft	20A	32.5	23.5	T_c	FB-1	60
2	Forward	21A,55B	80	18	T_c, R	None	0
2	Aft	22A	80	18	T_c	FB-520	80
5	Forward	23A,59B,54B	118	18	T_c, R,C	Temp-Coat	50
5	Aft	24A	118	18	T_c	FB-2	60
6	Forward	134A,52B	84	23	T_c, R	None	0
6	Aft	135A	84	23	T_c	FB-2	80
7	Forward	138A	8	16	T_c	Temp-Coat	40
7	Aft	141A	8	16	T_c	FB-520	60
7	Forward	140A,50B,51B	32	27	T_c, R,C	Temp-Coat	45
7	Aft	139A	32	27	T_c	FB-520	80
7	Forward	136A	16	66	T_c	Temp-Coat	35
7	Aft	137A	16	66	T_c	FB-520	70

Two fires were used for execution of the test. The largest was a combination of ALPHA and BRAVO materials located approximately 1.8 m (6ft) aft of the test bulkhead and slightly port of centerline. The BRAVO fuel for this particular fire was a 1gallon pool of heptane. This heptane pool was used to ignite the wood crib. The second fire was approximately 5 gallons of heptane contained in a 10" x 24" x 6" steel pan. This pool fire was placed directly against the aft side of the test bulkhead and centered on the vertical seam connecting panels #5 and #6.

In addition to the primary fires, a pile of ALPHA materials, newspaper, was placed on the deck and against the forward, non-fire side, of panel #6. This location placed the ALPHA materials directly opposite the 5-gallon heptane pool fire.

Schematics of the general test area can be seen in Figures. 2 and 3.

4. Experimental Procedure:

The test was conducted during work-ups for the FY 00 DC-ARM Demonstration (Ref. (7)) utilizing a wartime scenario fire. Material condition Zebra was set throughout the test zone, main deck to the 4th deck from frames 15-29. To simulate the test area being damaged by close proximity detonation of a medium sized warhead the following fittings were opened prior to ignition.

- ➤ Two hinged "blast panels" in the 2nd deck immediately aft of the test bulkhead.
- ➤ Ventilation dampers in the forward bulkhead of compartment 3-15-0
- ➤ Door 2-22-0

All ventilation in the immediate test zone was secured prior to ignition to satisfy Damage Control Doctrine regarding ventilation in the area of a shipboard fire.

Data collection, actual commencement of the test, was started approximately 2 minutes prior to ignition of the test fires. This is standard test procedure required to collect ambient background data. Ignition of the test fires was accomplished manually by members of the Safety Team.

The BRAVO pool fire, located against the test bulkhead, consumed its fuel and burned out approximately 15 minutes after it was ignited. The Alpha fire was manually extinguished approximately 30 minutes after it was ignited. Data collection was secured approximately 45 minutes after commencement of the test.

5. Results:

- ➤ A small portion of the coatings on the aft surface of panels #5 and #6, low and directly in front of the test fire, exhibited limited intumescent response due to immediate and direct flame impingement from the heptane pool fire.
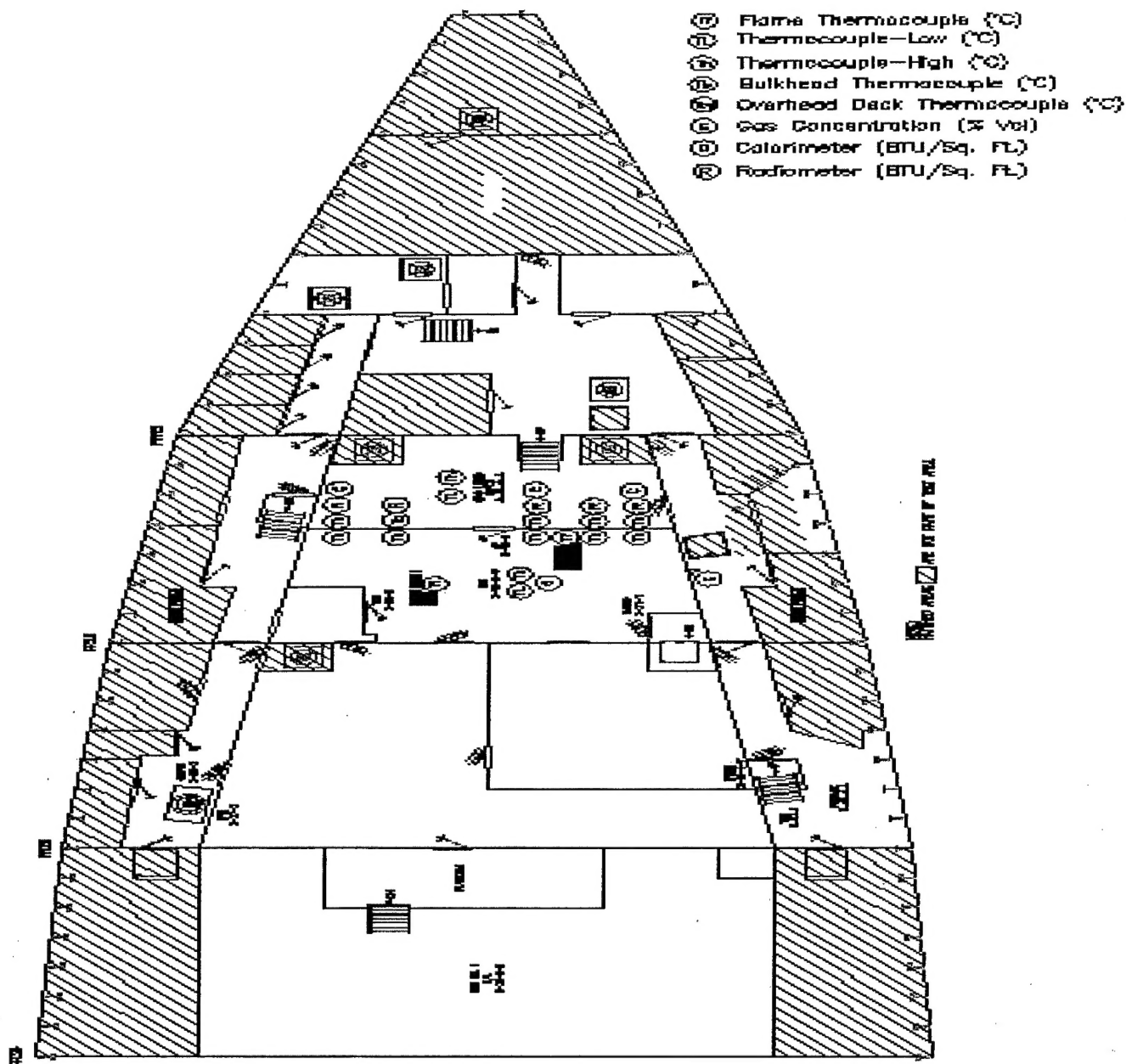
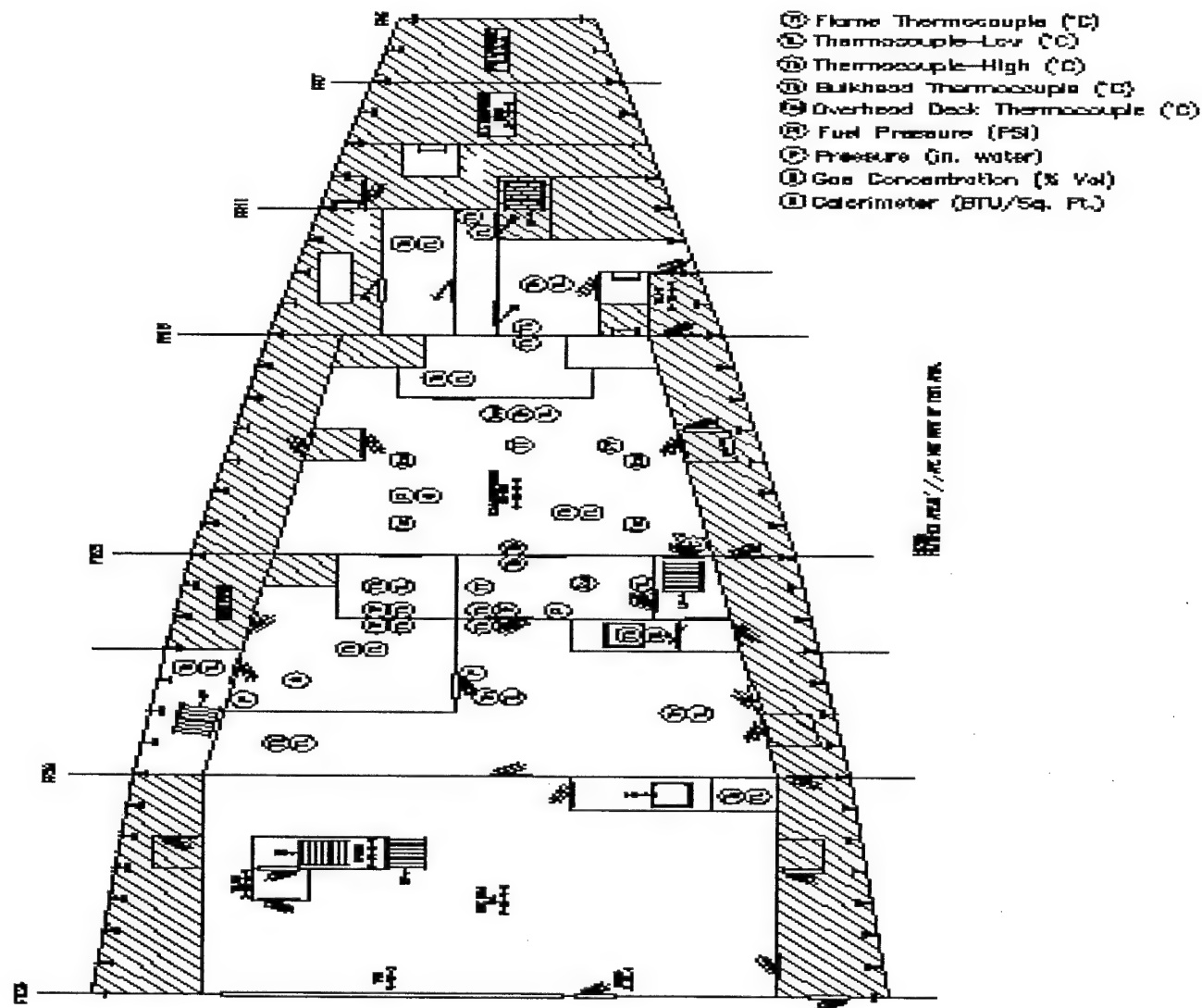**Figure 2. Plan View Schematic of Second Deck Instrumentation Layout**

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Figure 3. Plan View Schematic of Third Deck Instrumentation Layout

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➤ The predominant response of the fireside coatings on panels #5 and #6 was blistering.

➤ Coating surfaces receiving no direct flame impingement, panels 1-4 and 7, either blistered or exhibited no reaction at all.

➤ No surface temperature, on the non-fire side of any test panel, exceeded 133 °C (271 °F) at any point during the test.

➤ Maximum temperature of the non-fire side surface does not appear to be a function of surface treatment. With the limited data available, there is no way to prove that the Temp Coat product had any affect on the temperature profile.

➤ Following conclusion of the test, a propane torch flame was applied to several arbitrarily selected locations, on the fireside surfaces, of each test panel. The locations included coating surfaces that had blistered and surfaces that showed no indication of response. The intention of this post test experiment was to determine whether there was still potential for an intumescent response from the test coatings. **No intumescent response was observed during this post test experiment.**

6. Discussion:

The fires used for this test represented potential threats resulting from a medium sized warhead detonating on the 3rd deck of ex-SHADWELL. The location and type of fire threat, based on warhead size, point of detonation, structural configuration and intended use of compartments in the PDA and APDA, was mathematically modeled (Ref. (8)). The test fires did not simulate the worst case. However, based on our current knowledge of internal ship conflagration dynamics, the level of thermal insult resulting from these fires should be considered realistic.

For the purpose of the following discussion, analysis will be restricted to the test bulkhead and coatings alone. Mechanisms associated with nearby structure radiation onto the surface of the bulkhead and coatings are outside the scope of consideration.

Panel 1: *Fire Barrier 1* vs. *Temp Coat*

Figures 4-6 are before and after photographs of the aft side of test panel 1 and the *Fire Barrier 1* coating. This panel was approximately 6.1 m (20 ft), at an angle of approximately 45°, to the port side of the ALPHA fire.

Figure 4 shows the pre-test condition of this coating to be smooth and unblemished. Figures 5-6 show this coating blistered after being exposed to a radiant heat insult for a period of approximately 32 minutes. This blistering started at approximately 0.91 m (3 ft) above the deck and extended to the overhead. The white area near the top of Figure 6 is the result of a blister being cut open following the test. The white surface seen is a sub-layer of bulkhead coating. This opened blister was approximately 1.7 m (66 in.) above the deck. The application map supplied by the
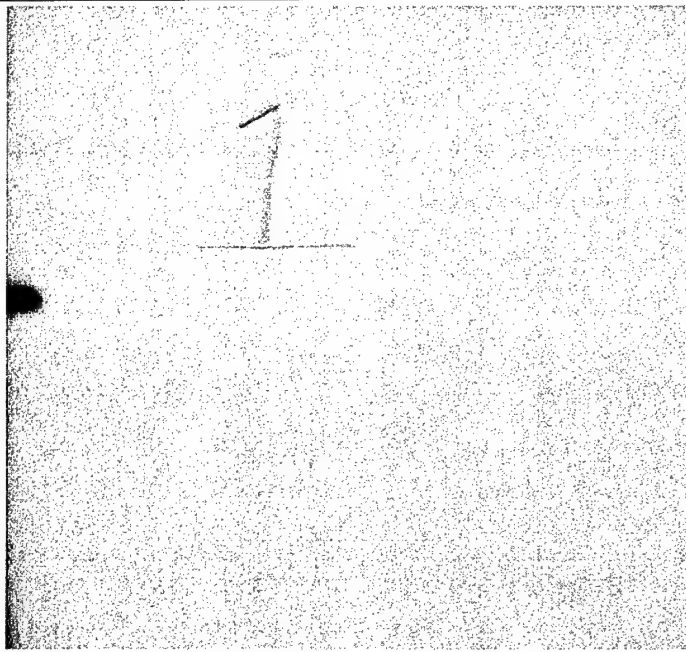
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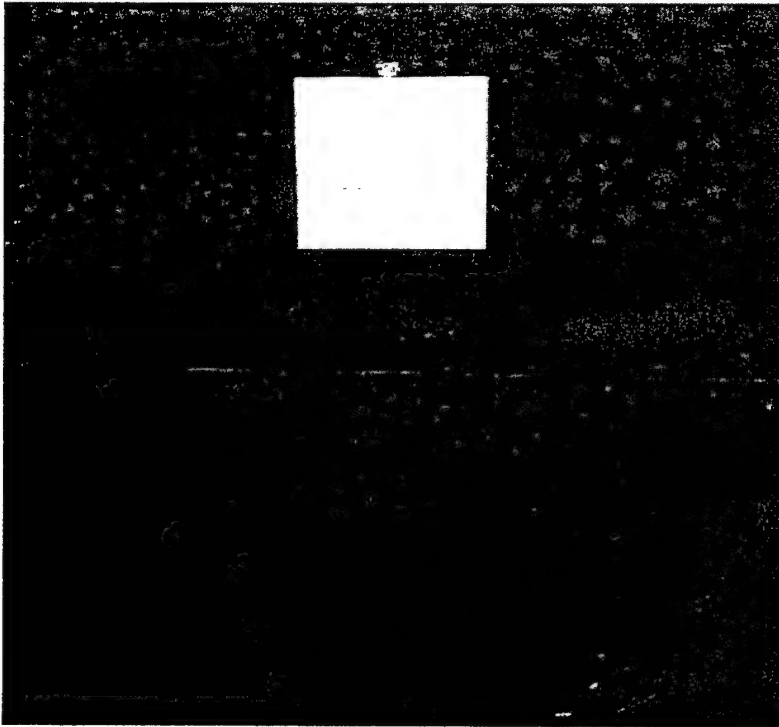**Figure 4. Fire Barrier-1, Pre-Test Condition**

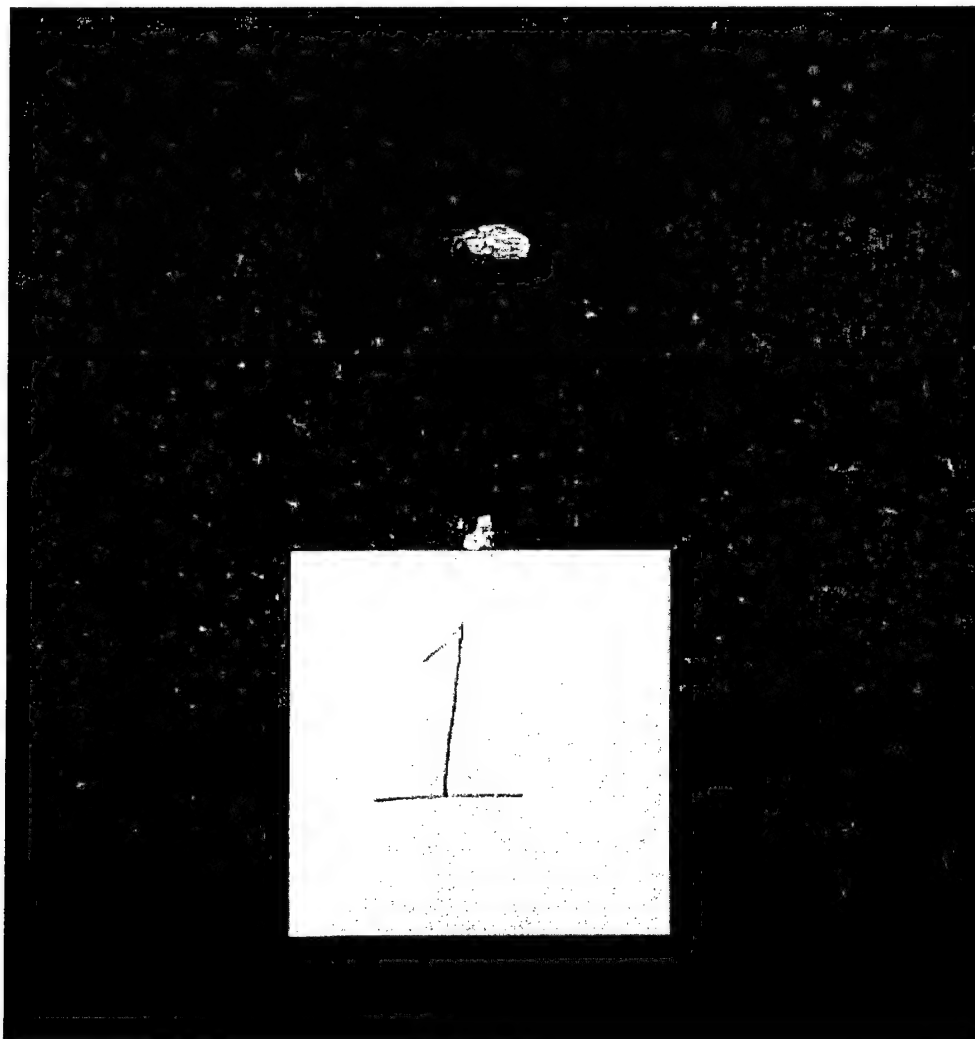**Figure 5. Fire Barrier- 1, Post-Test Condition**

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Figure 6. Fire Barrier-1, Close-Up, Post-Test

coating manufacturer (Figure 1) indicates the *Fire Barrier 1* coating was approximately 65 mils at this position on the test panel.

Figure 7 shows the panel surface time/temperature plots of the thermocouple pair for this panel. The upper trace is the temperature history on the aft, fireside, of panel 1. The lower plot is the temperature history on the forward, non-fire side, of the same panel. The lower trace reveals a 24°C (44 °F) drop in temperature between 21 and 23 minutes. At approximately the same time this drop in temperature occurred the calorimeter monitoring the forward side of this panel (upper trace in Figure 8) measured an increase in the total heat flux leaving the forward surface.

Applying equation 4 to the pair of data traces in Figure 8, subtracting the lower radiant flux trace from the upper total heat flux trace, will produce the convective heat flux component associated with this forward surface. The average increase in convective heat flux between the 21 and 23-minute marks was approximately (0.022 Btu/ft^2/hr). This represented a two-fold increase in the convective flux rate. The convective flux component increased again, at approximately the 25-minute point, an average of (0.020 Btu/ft^2/hr) and remained at this level until the ALPHA fire was extinguished. The lower, radiant flux, trace of Figure 8 can be seen to remain nearly unaffected during this time frame and, indeed, throughout the entirety of the test.

An increase in the convective heat transfer rate can be seen in the trace for calorimeter instrumentation (Figure 8) commencing at approximately 21 minutes. There are two possible explanations for this observed phenomena. The first possibility is that some fitting was opened, forward of the test bulkhead, which allowed ventilation currents to start. This would imply that either QAWTD 2-17-1, ventilation damper 2-15-1 or ventilation damper 2-15-2 was opened however the temperature profile for the forward compartment (Figure. 9) doesn't support this argument. In fact, according to written test records, QAWTD 2-17-1 and the two previously mentioned ventilation dampers remained closed throughout the entire test. Clear evidence of a change in these settings can be seen in Figure 9 when both high and low compartment temperature profiles drop precipitously at approximately 39 minutes. The reason for this sudden drop in temperature was opening of QAWTD door 2-17-1 and ventilation damper 2-15-1, by a member of the Safety team, to facilitate post-test cooling of the area. Another possible explanation for the increase in convective heat flux observed is that localized eddy currents began to dominate and convective cooling increased.

The test bulkhead was bounded on all sides by deck, overhead and bulkhead steel. The temperatures of these boundary structures increased at different rates due to existence of the test fires. By virtue of all these surfaces being heated at different rates an asymmetric free-convection velocity distribution would have developed (Refs. (9)-(10)).

Prior to the 21-minute mark of the test, both forward and aft side, thermocouples display a nearly identical rate of increase at approximately 2 °C/min (3.7 °F/min) (Figure 7). From 23-30 minutes of the test, the aft side thermocouple continues to register a nearly identical 2 °C/min (3.7 °F/min) rate of rise while the forward side thermocouple registers a 0.4 °C/min (0.72 °F/min) rate of rise. The reduced rate of rise in forward surface temperature, beyond the 23-minute point, is further indication that a localized increase in convective cooling had occurred.
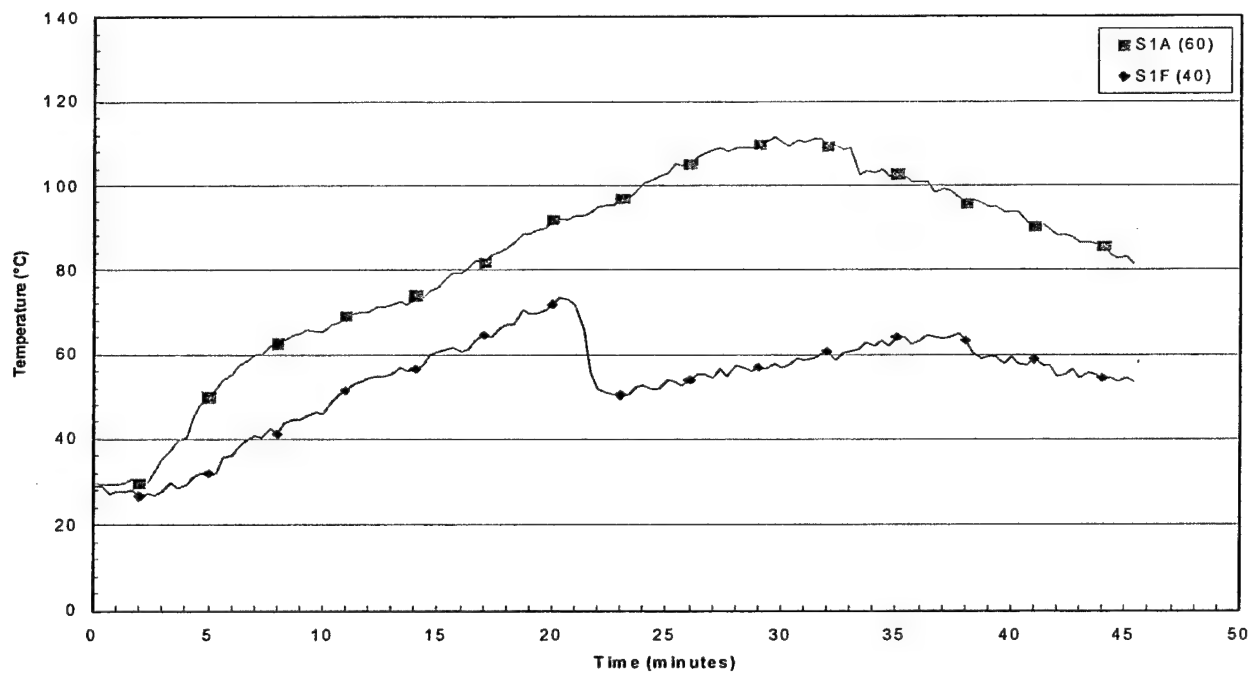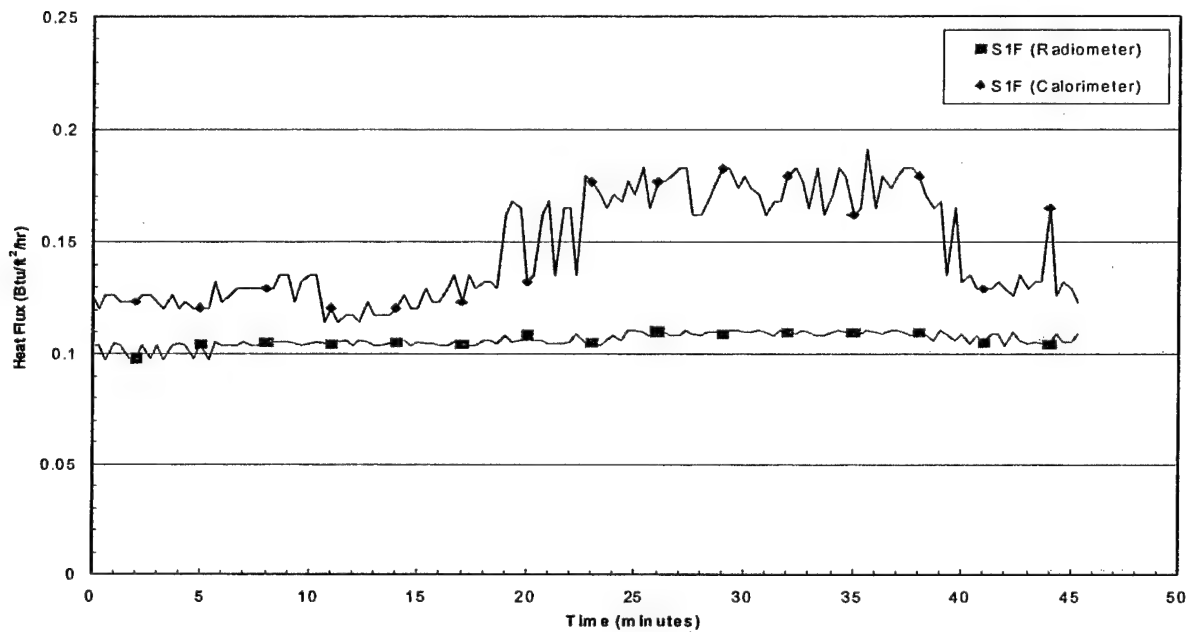
Figure 7. Temperature Profile, Panel #1

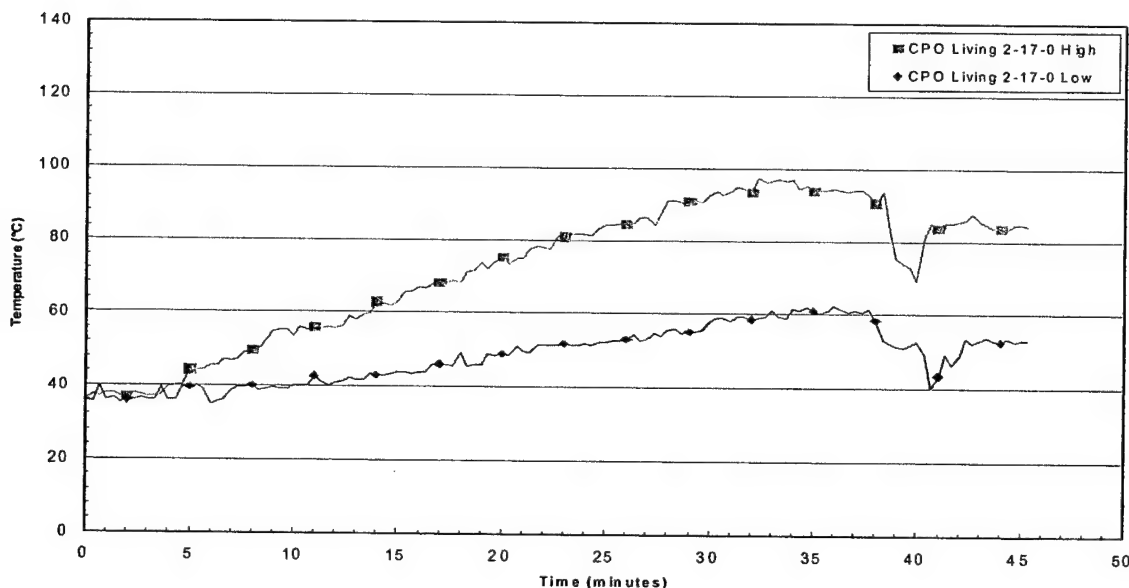**Figure 8. Heat Flux Profile, Panel #1**

Figure 9. CPO Living Air Temperature Profile

The upper data plot in Figure 8 is the sum of radiant and convective flux. The thermally driven velocity profile just described would have increased the convective heat transfer coefficient (h) across the forward surface of test panel 1. The increase in (h) would have increased the magnitude of the convective heat flux measured on the forward surface of this panel. This is exactly what is shown implicitly by the raw data and explicitly when equation 4 is applied to these two data traces.

Figure 9 shows upper T increasing at greater rate than lower. This <u>implies</u> upper/lower layer interaction. However, shielded TC separated by NA' vertically will not provide conclusive data for explicit analysis.

Figures 10-12 are before and after photographs of the product *Temp Coat*. This coating was applied to the forward side of panel 1. Other than one area of discoloration, this coating showed no physical reaction to the test fire. The area of discoloration, seen close-up in Figure 12 occurred near the 55 mil and 70 mil thickness. The elliptical structure rising from the top of a nearly circular point of discoloration seems to indicate a surface stain resulting from a point source of smoldering combustion.

Panel 2: *Fire Barrier-520* vs. Bare Steel

Figures 13-15 are before and after photographs of the coating *Fire Barrier-520*. The test panel was located approximately 4.6 m (15 ft), at roughly 30°, to the port side the ALPHA fire. Figure 14 show the coating produced very little blistering and no cracking. The coating did not intumesce. Considering that the spatial separation between panel 2, panel 1 and the large ALPHA

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fire were similar, it seems logical to conclude the *Fire Barrier* 520 coating is capable of sustaining higher levels of radiant insult than the fire barrier 1 coating before bubbling.
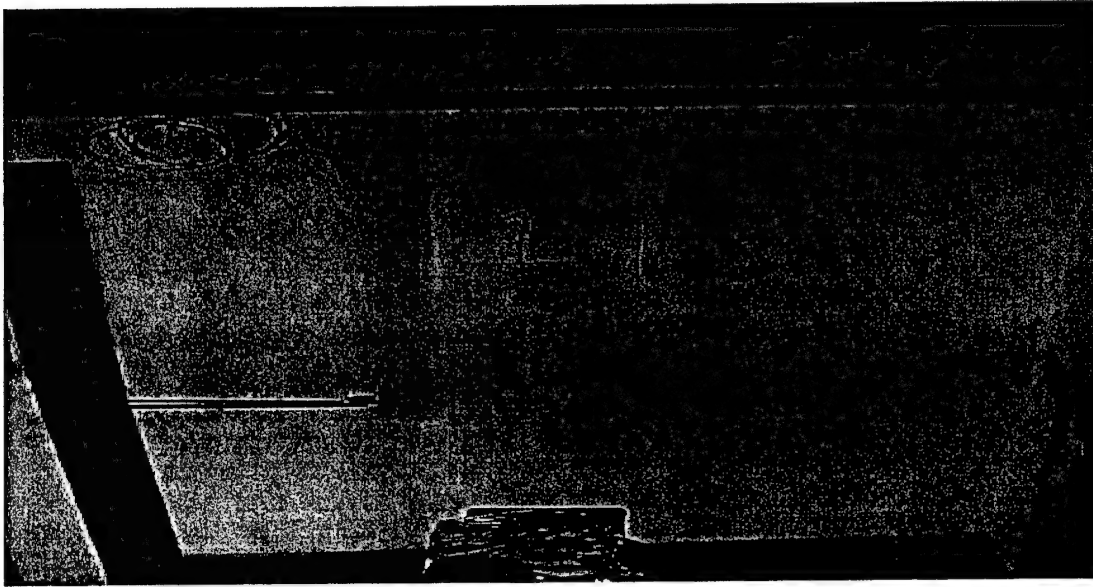
Figure 10. Temp Coat Pre-Test Condition
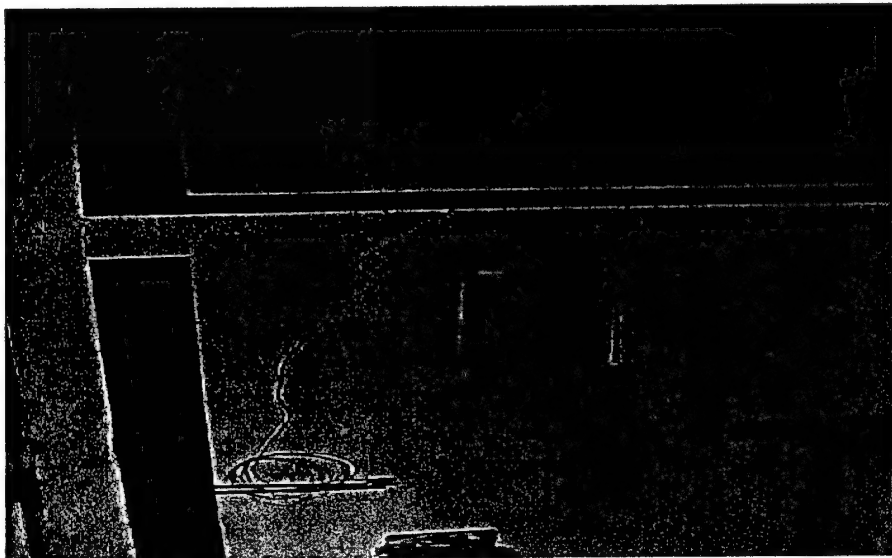
Figure 11. Temp Coat Post-Test Condition
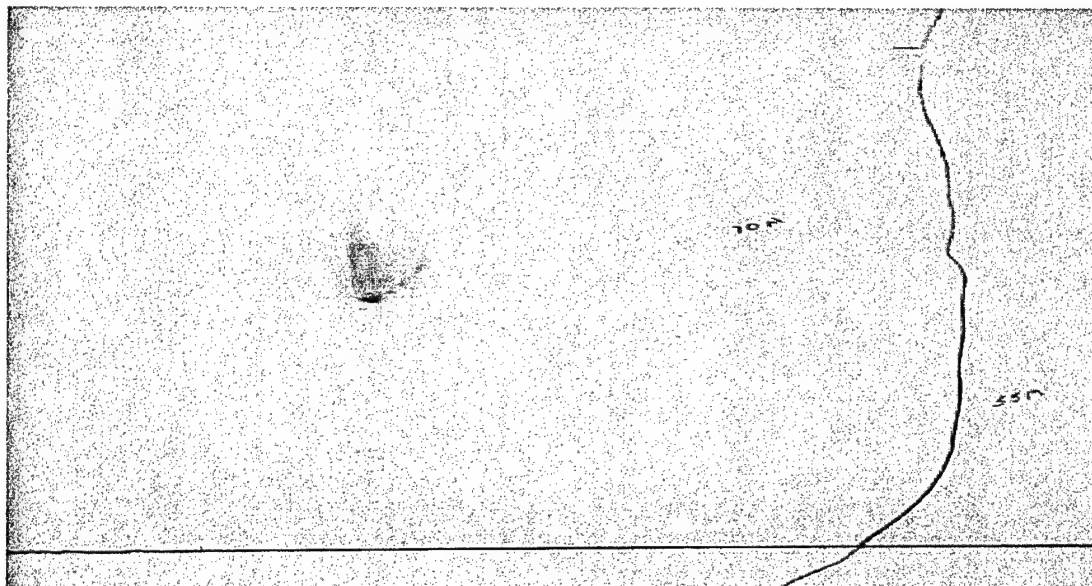
Figure 12. Temp-Coat, Close-Up, Post-Test
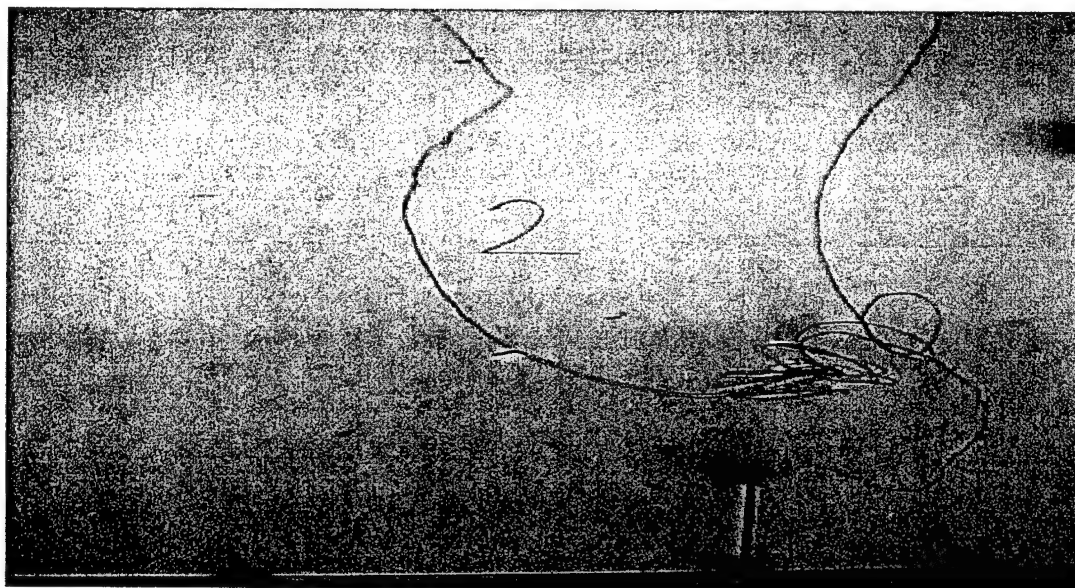
Figure 13. Fire Barrier 520 Pre-Test

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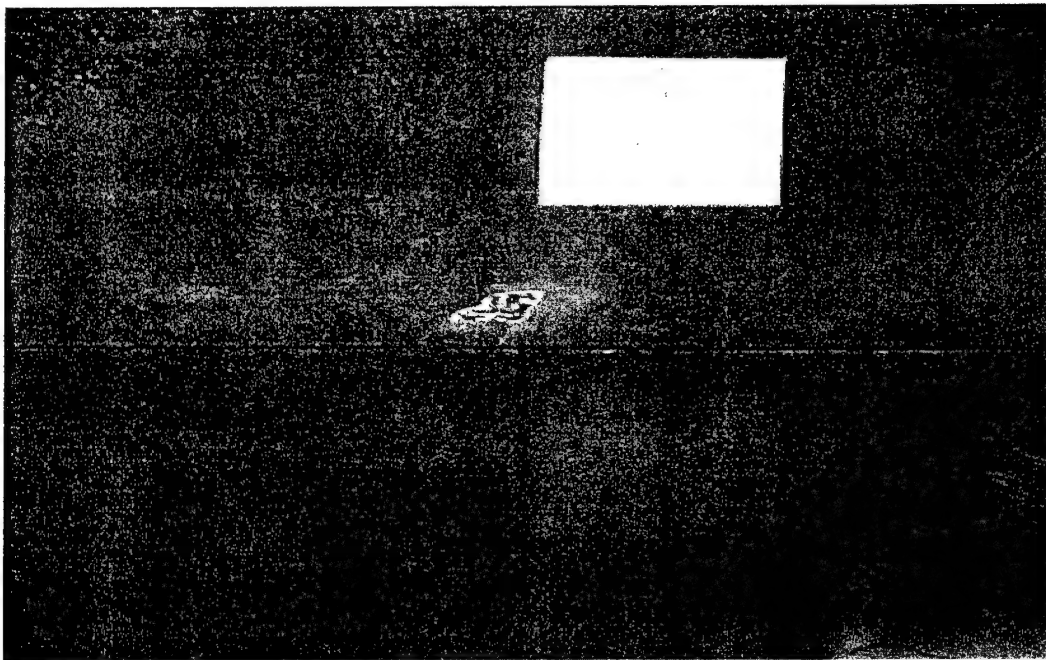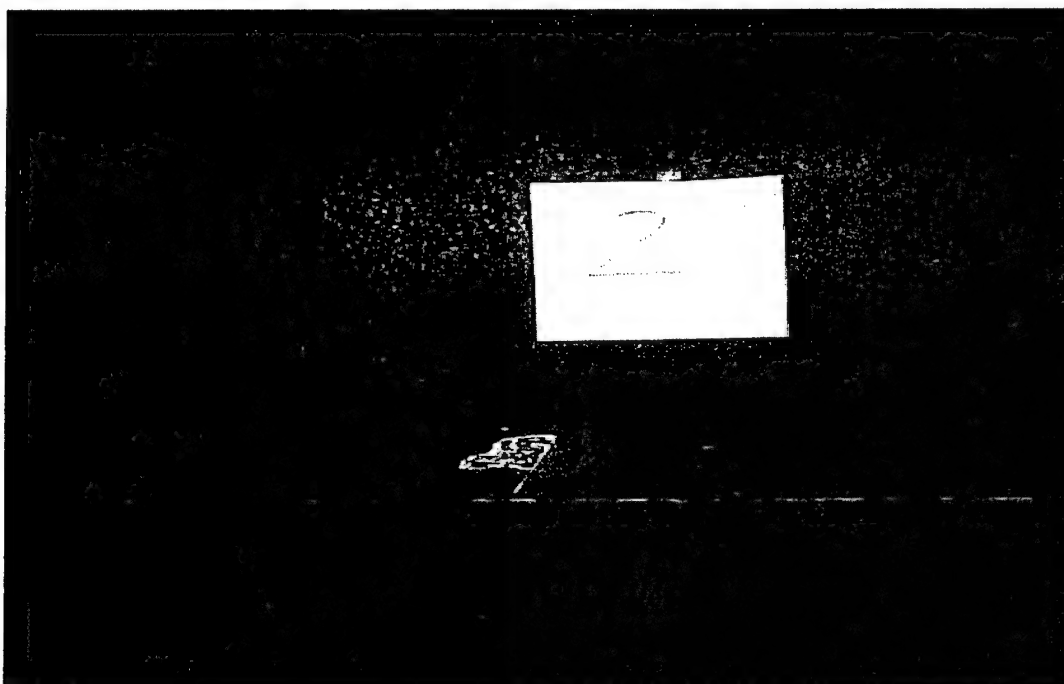**Figure 14. Fire Barrier 520 Post-Test Condition**

Figure 15. Fire Barrier 520 Close-Up, Post-Test

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Figure 16 shows the time/temperature plot of the thermocouple pair for this panel. The temperature differential, between forward and aft thermocouple, was 23 °C (73 °F) at 10 minutes and 38°C (100 °F) at 27 minutes. The aft surface temperature maintained a consistent 2.4 °C/min (4.3 °F/min) rate of rise from approximately 10 minutes through 27 minutes. The forward surface temperature maintained an almost uniform 1.5 °C/min (2.7 °F/min) rate of rise for the same period of time.

The forward surface of this panel was uncoated. Examination of Figures. 17 and 18 show there was no physical change in condition of this surface. Figure 19 is a plot of radiant heat flux measured from the forward surface of this panel. The erratic nature of the trace, commencing at about 13 minutes, seems to indicate development of "hot spots" and a non-uniform temperature distribution across the untreated surface. This would have been the result of non-uniform application thickness of the *Fire Barrier-520* coating on the opposite side of the panel. The increase in radiant flux measured at approximately 20 minutes, (0.052 Btu/ft^2/hr) to (0.092 Btu/ft^2/hr), looks significant when taken by itself. However, the maximum measured radiant flux for this panel remained below the maximum radiant flux (0.105 Btu.ft^2/hr) measured on the forward surface of panel 1. This seems to indicate that a 90 mil thickness of *Fire Barrier*-520 will provide resistance to conductive heat transfer exceeding that of a combined 65 mil thickness of *Fire Barrier-1* and 50 mil thickness of *Temp-Coat*.

Panel 5: *Fire Barrier-2* vs. *Temp Coat*

Figures 20-24 are before and after pictures of the coating, *Fire Barrier-2,* applied to the aft side of panel 5. This panel was directly in front of the BRAVO pool fire. The coating would have been subjected to direct impingement of the flame throughout the entire time the heptane pool was burning. A small area of this coating, directly above the fire pan, showed some degree of intumescent response but not of the scope and uniformity that would have been expected. The coating surface was a mixture of hardened crust, blisters and a shallow, intumescent char. The dominant response of the coating on this panel was blistering. There was some post test indication this coating suffered minor cracking during the fire.

During a post test inspection, a small portion of the *Fire Barrier-2* coating was removed by cutting away a blister. Figure 24 shows this segment of the *Fire Barrier-2* coating. The surface exposed by cutting the blister is smooth and apparently unaffected by the thermal insult.
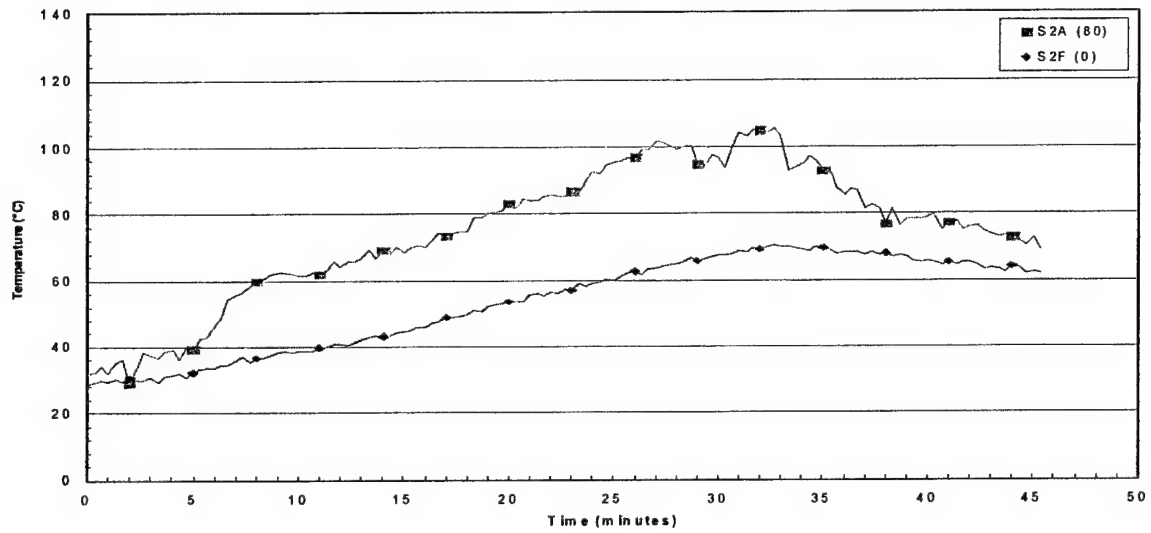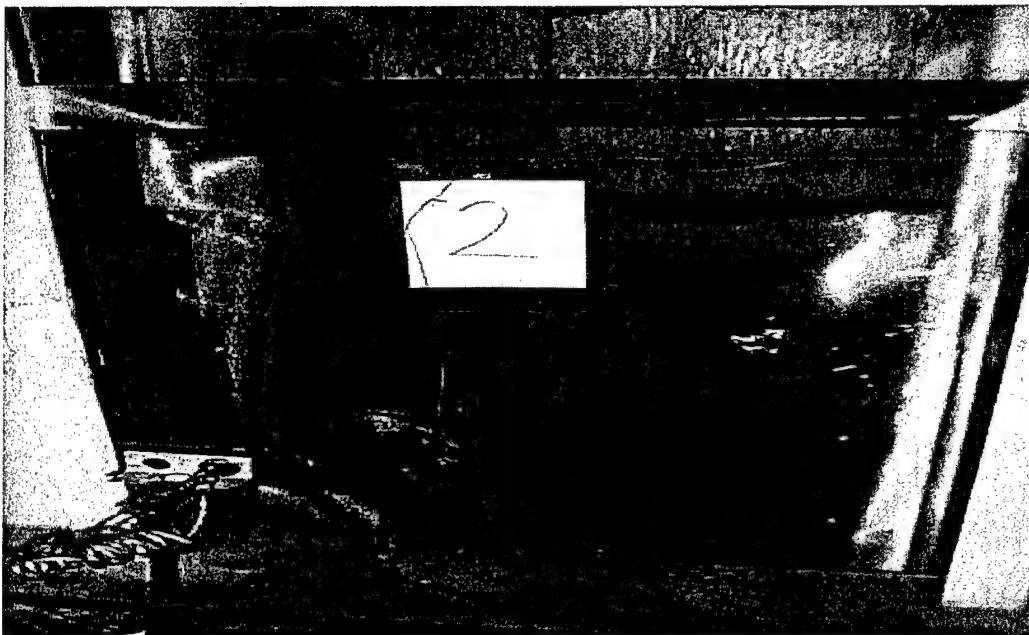
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Figure 16. Temperature Profile Panel #2

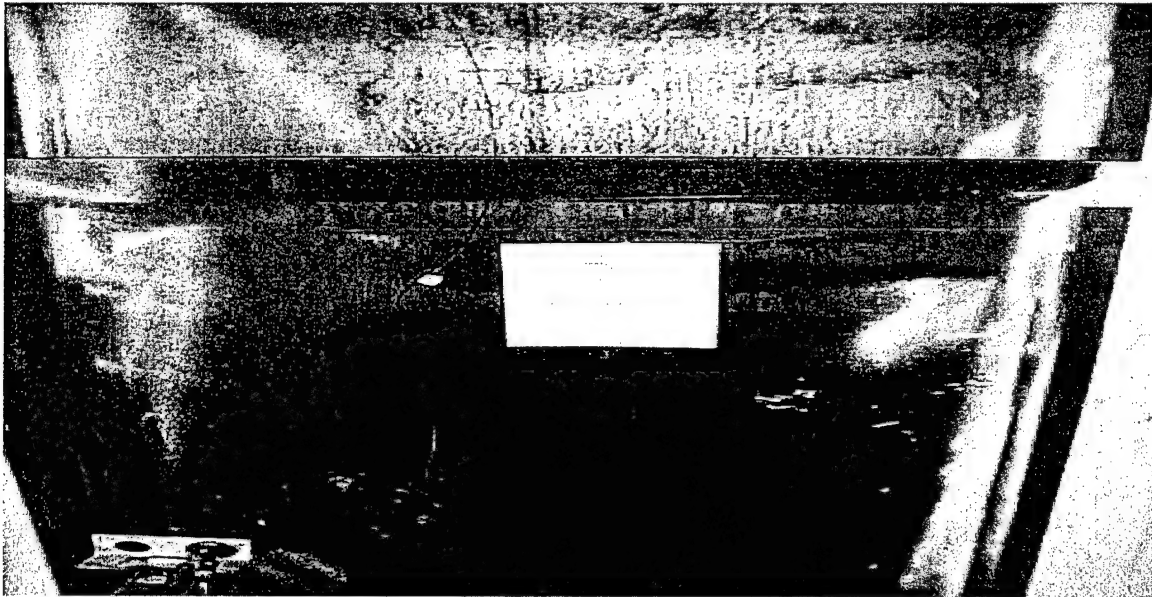**Figure 17. Pre-Test Forward Surface, Panel #2**

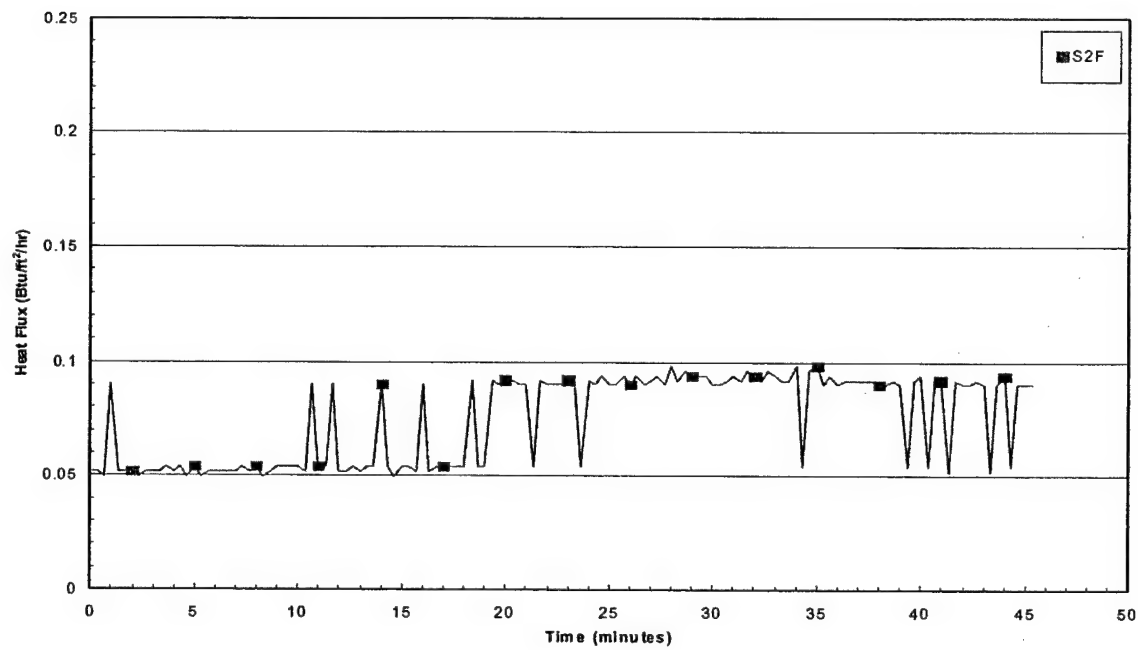**Figure 18. Forward Surface Panel #2, Post-Test**

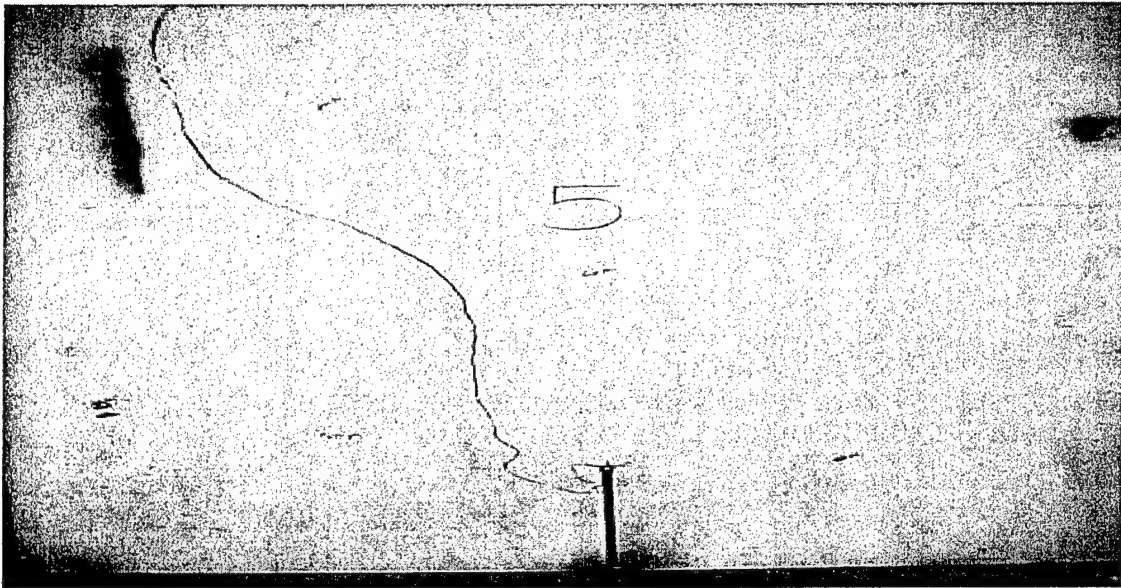**Figure 19. Heat Flux Profile Panel #2**

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Figure 20. Fire Barrier-2, Pre-Test Condition
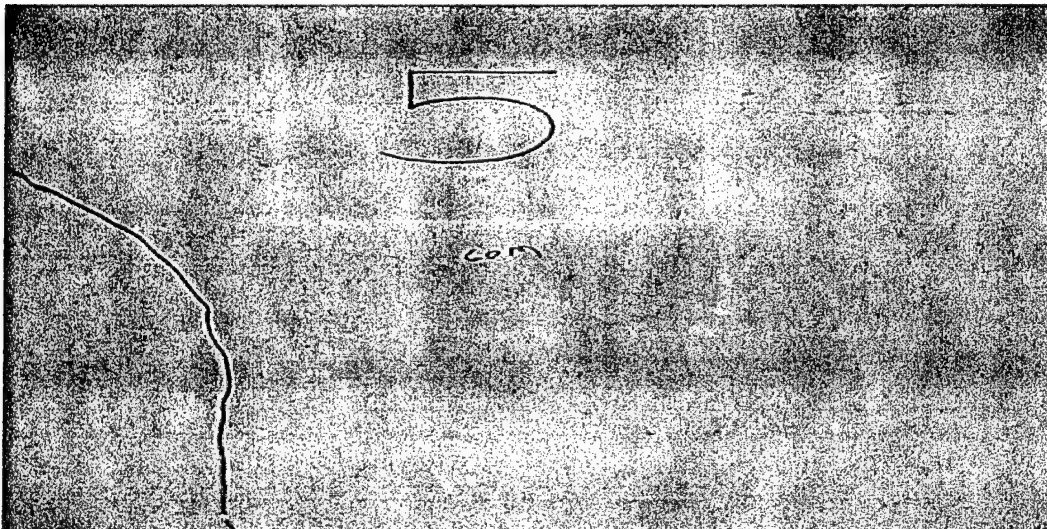

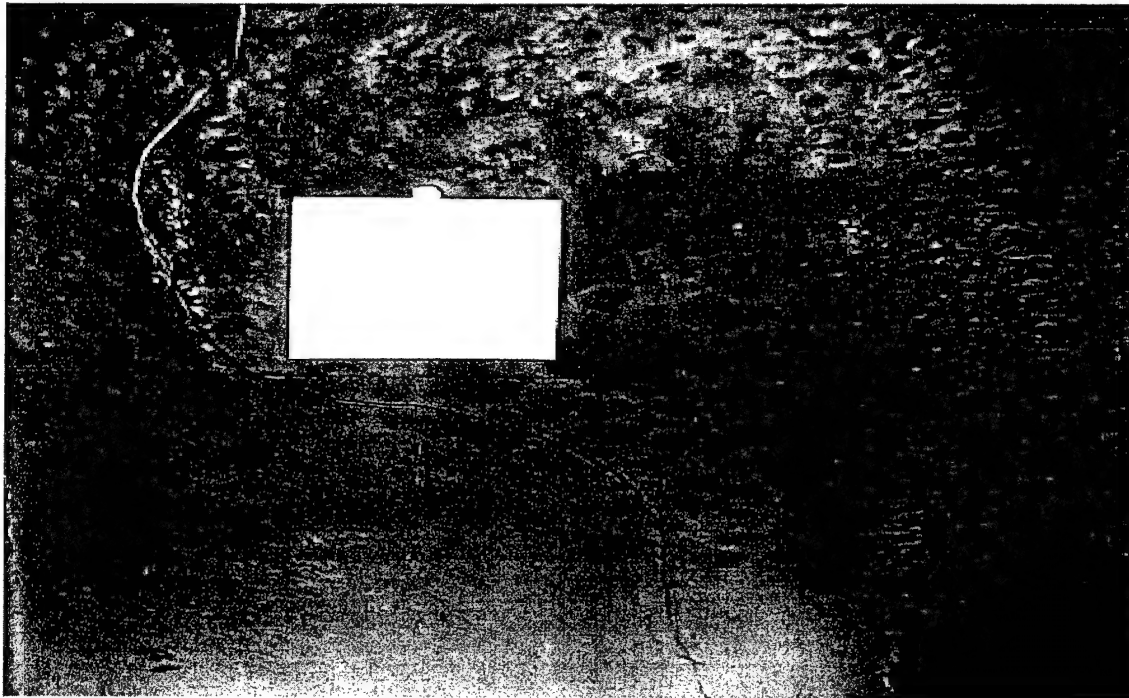**Figure 21. Fire Barrier-2, Pre-Test Close-Up**

Figure 22. Fire Barrier-2, Post Test

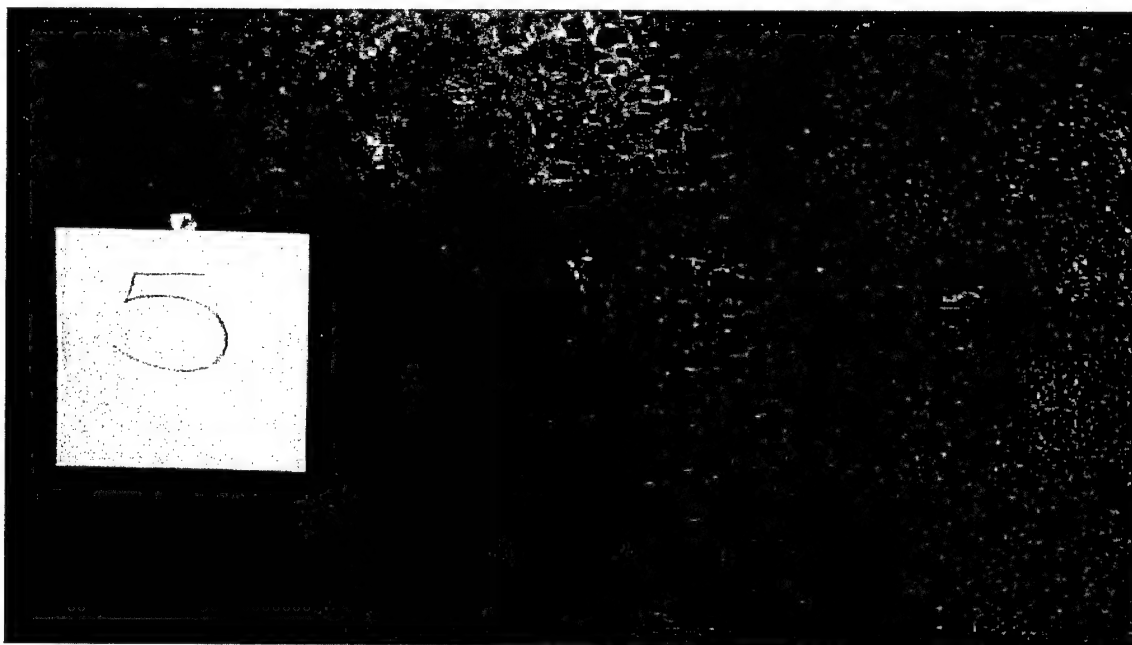**Figure 23. Fire Barrier-2, Close-Up**

Figure 24. Fire Barrier-2, Detail View of Cut-Away Blister

Figure 25 shows the fireside bulkhead thermocouple rising rapidly from an ambient temperature of 31 °C (88 °F) to a maximum of 330 °C (594 °F) and then back to a temperature of approximately 153 °C (307 °F) in a period of approximately 6 minutes. Based on post test inspection of the coating it has been determined that the initial rate of temperature rise due to the 5 gallon heptane pool fire, approximately 75 °C/min (126 °F/min), was insufficient to activate a large scale intumescent response across the aft surface of this particular panel.

There are two possible explanations for the rapid rise and fall of the fire side surface thermocouple temperature profile (Figure 25). The first explanation is localized burning of evolved organic vapors. The second explanation is a fluctuating burn rate of the 30 cm x 76 cm (12 in. x 30 in.) heptane pool. The current understanding is that fire compartment ventilation has a measurable impact on pool burning rates, heat release rates and species production (Refs. (11) - (12)). An increase in products of incomplete combustion (smoke, CO) is some indication that there was a decrease in ventilation to the fire.

For the test being discussed, a cyclic variation in fire compartment ventilation seems to be indicated by the time history of compartment CO concentration. The top trace of Figure 26 shows a rise and fall of CO concentration high in the fire compartment. A decrease in ventilation also seems to be indicated by a decrease in burning rate of the heptane pool, reflected in the top trace of Figure 27, and a decrease in burning rate of the combined ALPHA/BRAVO fire as seen in the upper thermocouple trace of Figure 28. The upper thermocouple trace in Figure 27 is data collected approximately 152 cm (60") above the seat of the combined ALPHA/BRAVO fire at frame 20.

Further indication of a ventilation restricted burn can be seen in the bottom two traces of Figure 29. The sampling locations were 2.5 m (96") above the fire compartment deck and approximately 0.3 m (12") below the seats of the test fires. There were two large penetrations in the deck of the fire compartment immediately aft of the heptane pool. These large penetrations would have allowed free communication of the atmospheres between compartments 2-17-0 and 3-15-0. The oxygen measurement attributed to compartment 3-20-2 was, physically, directly below and between the seats of both test fires. The oxygen profile for the 3-20-2 location would have been, due to physical proximity alone, a close approximation of the available oxygen at the seats of these fires.

Timing of the decrease in compartment oxygen concentration, initial increase and peaking of the CO concentration, burning rate fluctuations of both test fires and bulkhead temperature decrease are at, plus or minus 1 minute, 7 minutes in the test timeline. This data indicates it took less than 5 minutes, from the moment of ignition, for the fires to consume enough oxygen to have a measurable and limiting impact on compartment temperature profiles, bulkhead surface temperature profiles and test fire burning rates. The availability of oxygen to support the test fires was limited by fixture and ventilation settings. Considering that fixtures were set to replicate damage predictions and ventilation was set in accordance with Damage Control doctrine, it seems logical to conclude the test fires could not have grown any further. As a result, the conditions produced by these fires became as severe as the physics of compartment burning would allow.

After the brief temperature "spike," the forward and aft side thermocouple exhibited a nearly identical rate of rise, 1.3 °F/min), up to the 29 minute point in the test. The temperature

differential between aft and forward surface of this panel remained a nearly constant 49^0C (120^0F) from 7-29 minutes of the test.
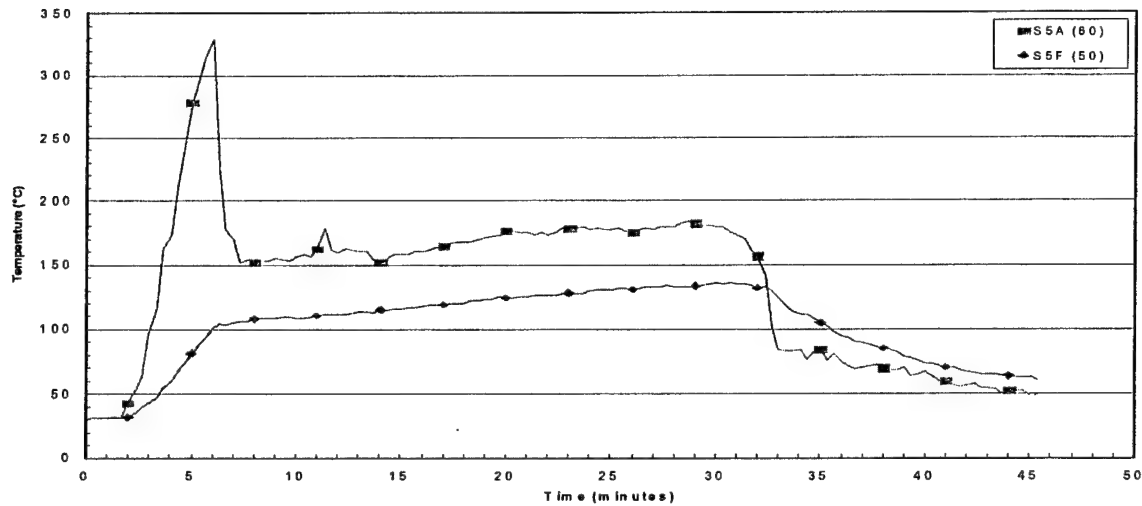

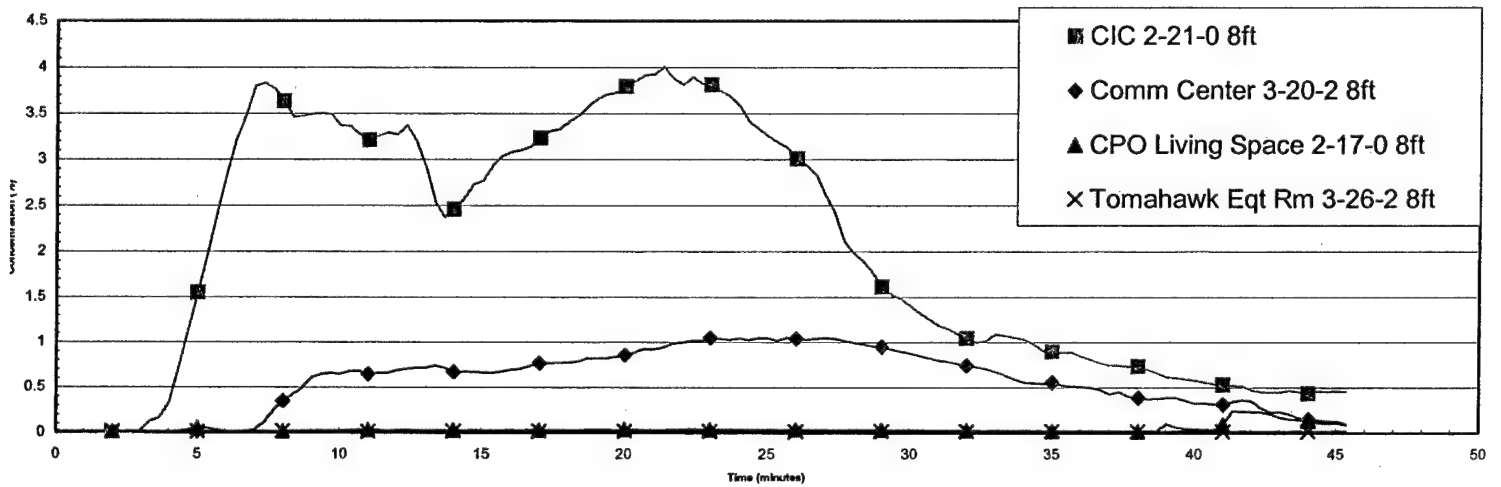**Figure 25. Temperature Profile Panel #5**
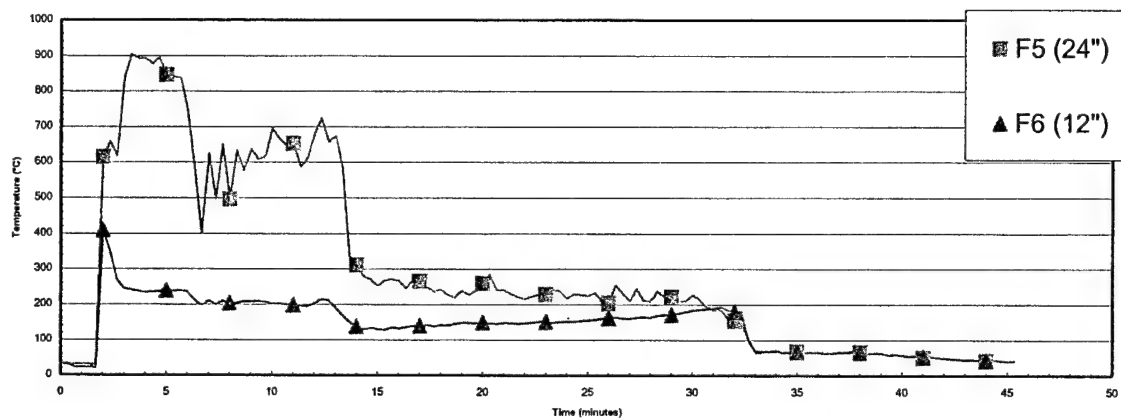

Figure 26. CO Concentration Profiles

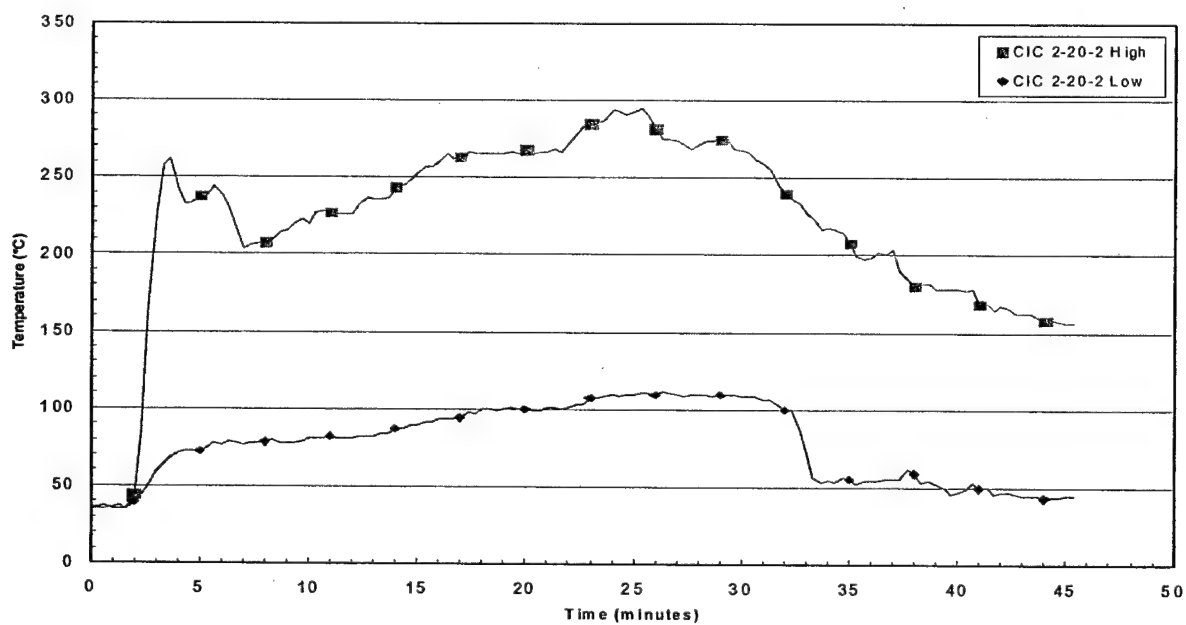**Figure 27. Wood Crib Temperature Profiles**
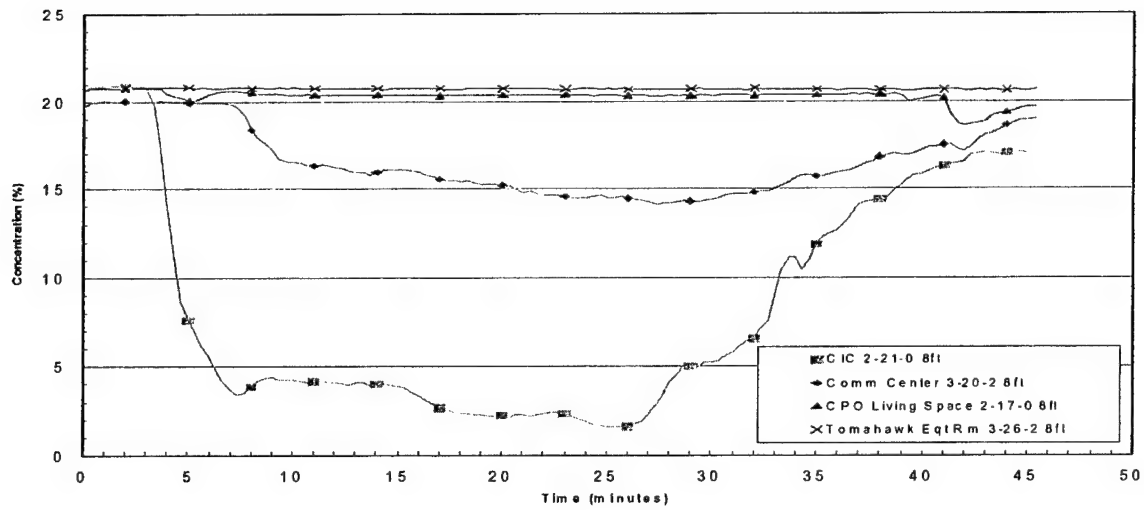

Figure 28. Compartment Air Temperature Profiles
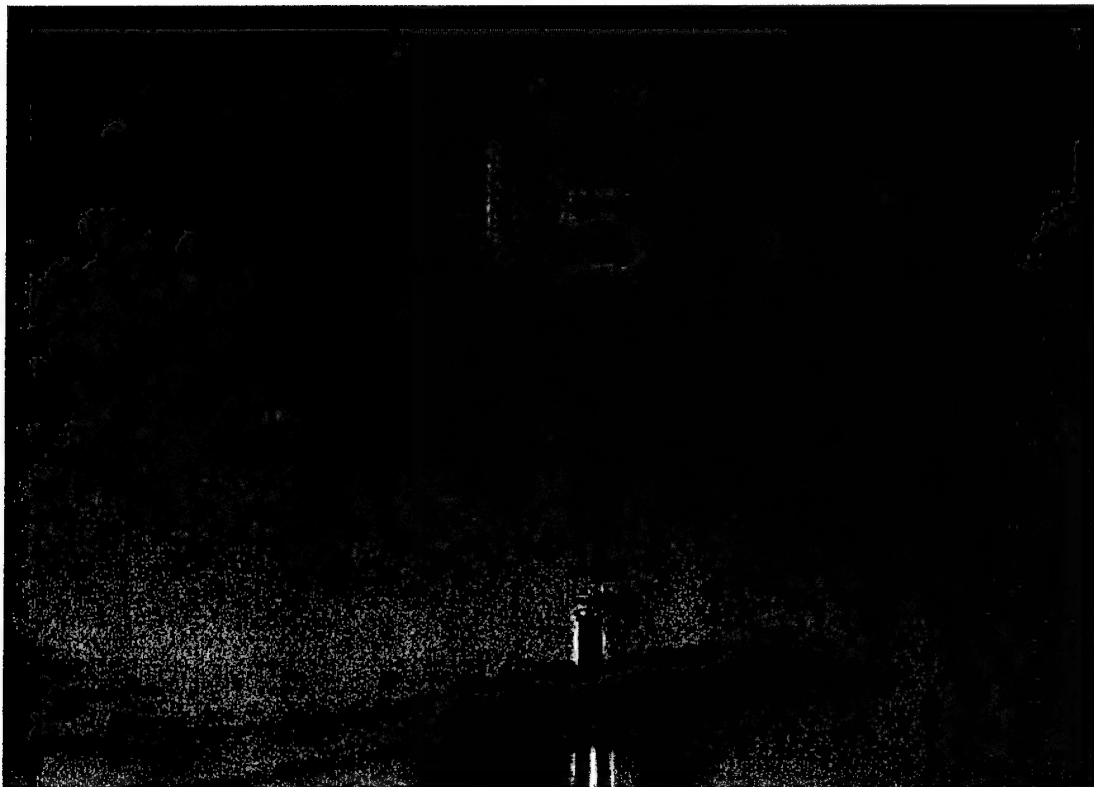
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Figure 29. Oxygen Concentration Profiles

Figure 30. Temp Coat Pre-Test Panel #5

Figure 30 and 31 are before and after pictures of the *Temp Coat* layer applied to the forward surface of this panel. Examination of Figure 31 will reveal a minor discoloration to a small area of this surface. Post-test inspection indicated this discoloration is super imposed atop a weld used to support the aft surface thermocouple. Existence of the weld "short circuited" the *Fire Barrier 520* coating by allowing a direct path for conduction of a heat to the forward side of the panel. With this minor exception, there was no visible impact from the heptane pool to the Temp Coat layer.
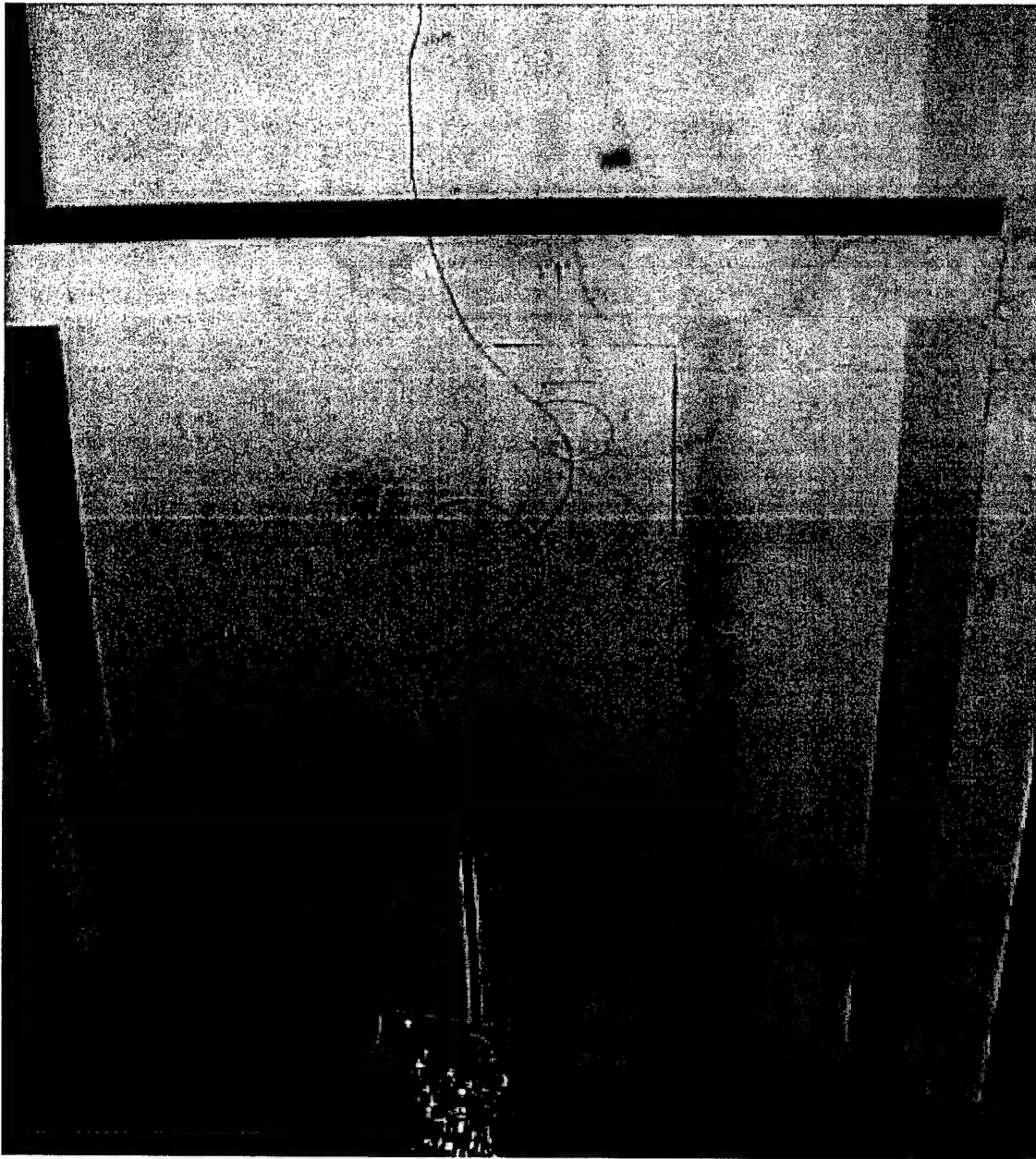
Figure 31. Temp Coat Post-Test Panel #5
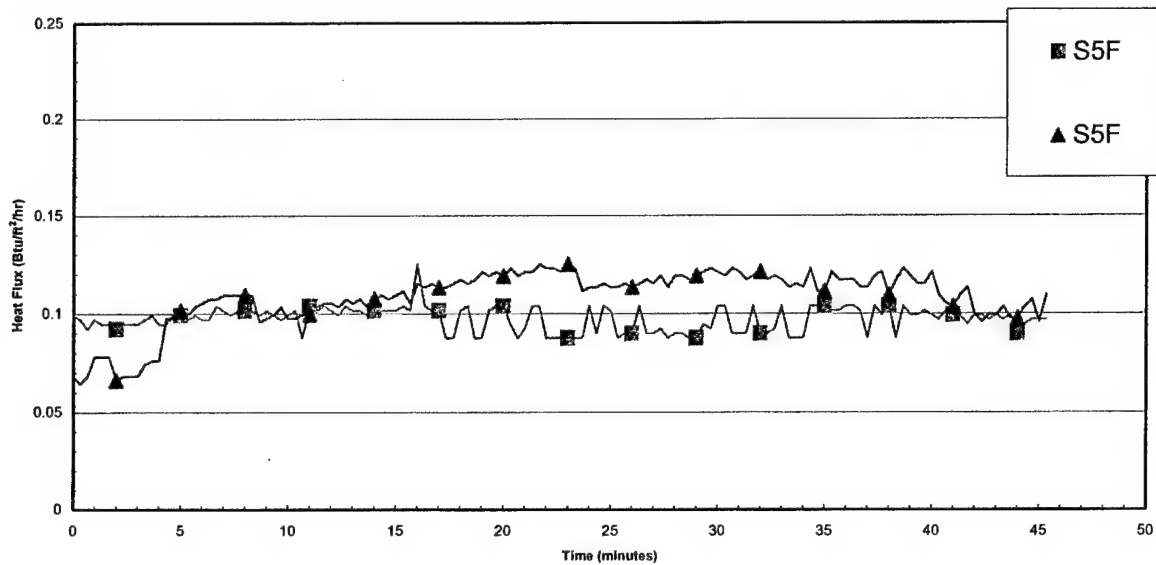
Figure 32. Heat Flux Profiles Panel #5

Figure 32 displays measurements of radiant and total heat flux from the forward surface of test panel 5. The erratic 12% fluctuation in the radiative flux component, lower trace, seems to correspond with the previously discussed increase in free convection.

Panel 6: *Fire Barrier-2* vs. Bare Steel

Figures 33-35 are before and after pictures of the coating *Fire Barrier-2*. As seen in the lower left-hand corner of Figure 34, this panel was immediately adjacent to the 5-gallon heptane pool fire. The entire surface of the coating, from deck to overhead, blistered very heavily. There was no indication of any cracking.

As seen in Figure 34, the aft side coating is heavily blistered around the entire surface to which the thermocouple was attached. As these blisters formed, they would have formed a void between themselves and the bulkhead steel. Due to porosity of the paint surface, these growing blisters would have drawn air into the increasing void. It's believed the resulting pockets of air, held within the paint blisters, impeded the rate of conductive heat transfer in the immediate vicinity of the aft side thermocouple.

The forward side thermocouple (Figure 36) exhibits an initial rise of 6.25 °C/min (11.25 °F/min), to a maximum of 84 °C (183 °F) prior to the 31 °C (88 °F) drop in temperature at 8 minutes. After this drop the forward side thermocouple exhibits a consistent 1.5 °C/min (2.7 °F/min) rate of rise through the duration of the test. The maximum temperature differential across this bulkhead is approximately 178 °C (352 °F), occurring at 20 minutes into the test.

The temperature differential across this test panel (Figure 36) became significant at approximately 8 minutes into the test when the forward side thermocouple registered a 30 °C (86 °F) drop in temperature. Post test inspection of the panel determined that the fireside thermocouple was within the blistered region. This can be seen by close inspection of the bottom left hand corner of Figure 34. At the same time the forward surface thermocouple recorded the temperature drop, the level of radiant heat flux leaving the forward surface was recorded at a fairly stable (0.082 Btu/ft2/hr) level (Figure 37). Considering the radiant flux leaving the forward side of the panel was stable during the recorded drop in temperature, it seems unlikely that loss of energy due to radiation would be the source of the observed temperature drop. In addition, the drop in temperature cannot be attributed to the previously discussed increase in free convection because the two events are separated by at least 12 minutes. The only remaining, logical, conclusion as to what influenced the measured temperature decrease, is blistering of the aft side coating.
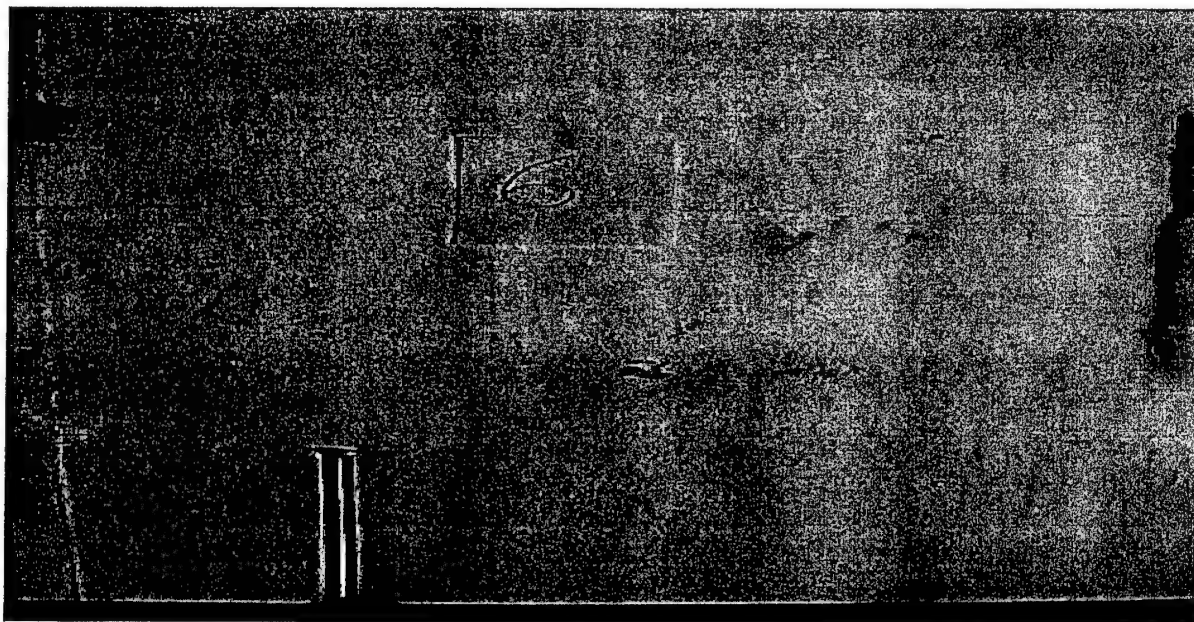
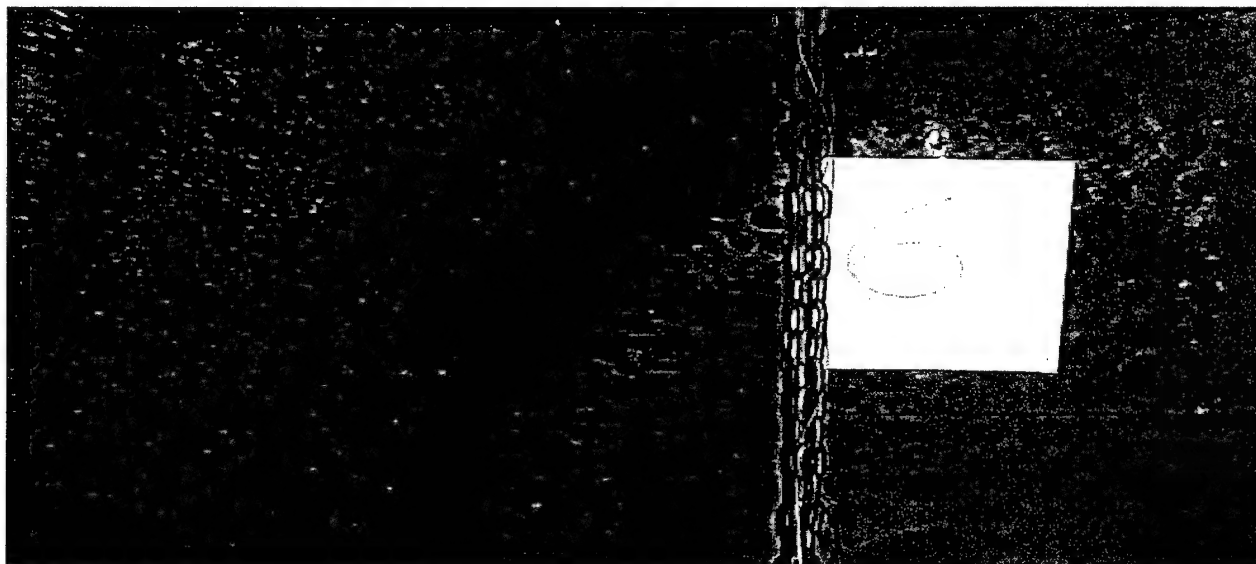**Figure 33. Fire Barrier-2, Pre-Test**

Figure 34. Fire Barrier-2, Post-Test

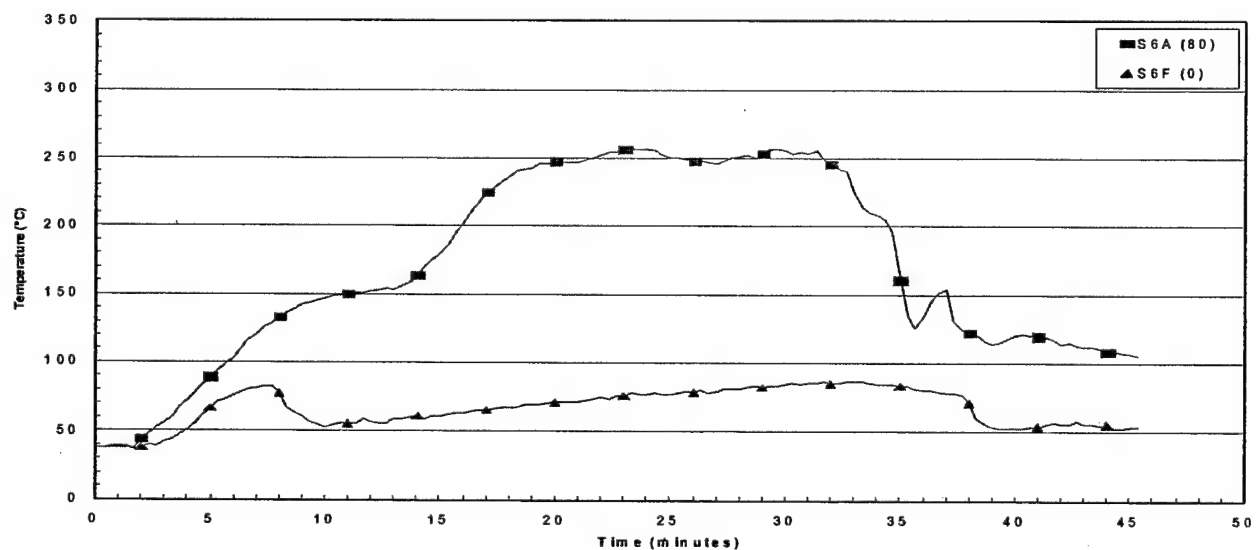**Figure 35. Fire Barrier-2, Close-Up, Post-Test**

Figure 36. Temperature Profile, Panel #6

Btu/ft2/hr level (Fig. 37) considering the radiant flux leaving the forward side of the pane was stable during the recorded drop in temperature, it seems unlikely that loss of energy due to radiation would be the source of the observed temperature drop. In addition the drop in temperature can not be attributed to the previously discussed increase in free convection because the two events are

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separated by at least 12 minutes. The only remaining, logical, conclusion as to what influenced the measured temperature decrease, is blistering of the aft side coating.

The bottom traces of Figure 25 and Figure 36 represent the surface temperature measurement on the non-fire side of panels 5 and 6 respectfully. As with panels 1 and 2, there appears to be no clear benefit afforded by the application of the Temp Coat product. In fact, the surface treated with Temp Coat reaches a higher maximum temperature than does the bare surface. This appears contradictory when one realizes the fire side of the untreated panel attained a higher, average surface temperature for a longer period of time than did the fire side surface of the Temp Coat treated panel. No clear conclusion could be reached to explain the phenomena because there was only one test conducted.

Figures 38-39 are before and after test views of the forward side of test panel 6.

Panel 7: *Fire Barrier-520* vs. *Temp Coat*

Figures 40-42 are before and after pictures of the coating *Fire Barrier-2*. This panel was located on the far starboard side of the test compartment. This panel was only subjected to a radiant insult due to its physical location. The coating, from 5' above the deck to the overhead, blistered very heavily. The coating exhibited no reaction below the 5' level. The post test inspection showed no indication the blistered coating was cracked.

Figures 43-45 are temperature measurements taken at 3 different locations within the same test panel. Figure 43, measured 16" above the deck shows a nearly identical rate of temperature rise at 2.2 °C/min (3.9 °C/min) for the forward thermocouple versus 2.4 °C/min (4.4 °F/min) for the aft thermocouple. The temperature differential, at the measurement point, between the forward and aft faces of this test panel was 6°C at 5 minutes, 15 °C at 17 minutes and 12 °C at 29 minutes.

Figure 44, measured 27" above the deck, shows the fireside bulkhead temperature rising at an average of 2.9 °C/min (5.3 °F/min) while the forward side temperature rises at 1.8 °C/min (3.2 °F/min). The temperature differentials were 13 °C (55 °F) at 5 minutes, 30 °C (86 °F) at 18 minutes and 40 °C (104 °F) at 29 minutes.

The bottom traces of Figure 43 and Figure 44 show there was little apparent benefit to application of the Temp Coat product. The maximum surface temperatures on the Temp Coat treated forward side of panel 7 (Figures 43 and 44), were not significantly different than those

measured on the bare, forward side of panel 6 (Figure 36). No correlation can be drawn between the measurements made at 66 inches above the deck on the forward side of panel 7 (Figure 45) and those made at 23 inches above the deck on the forward side of panel 6 (Figure 36).
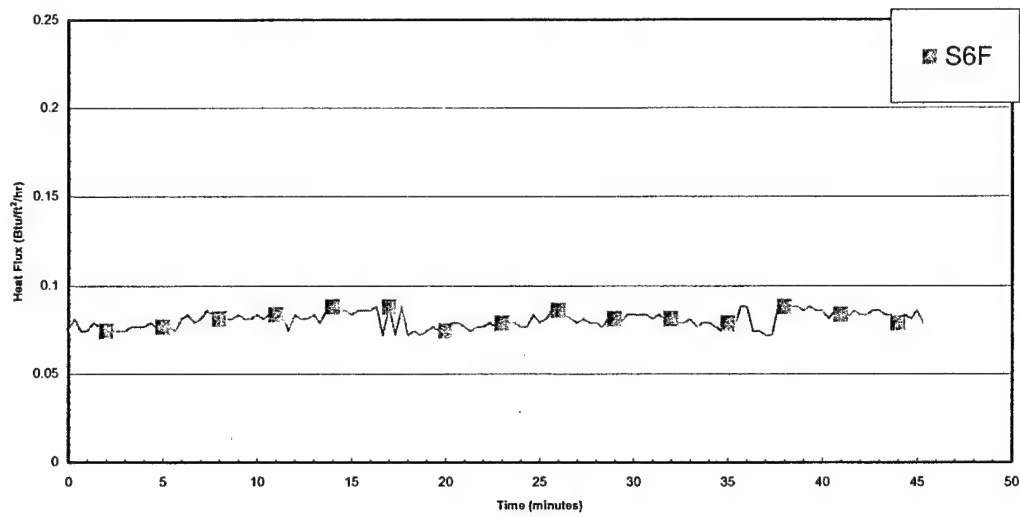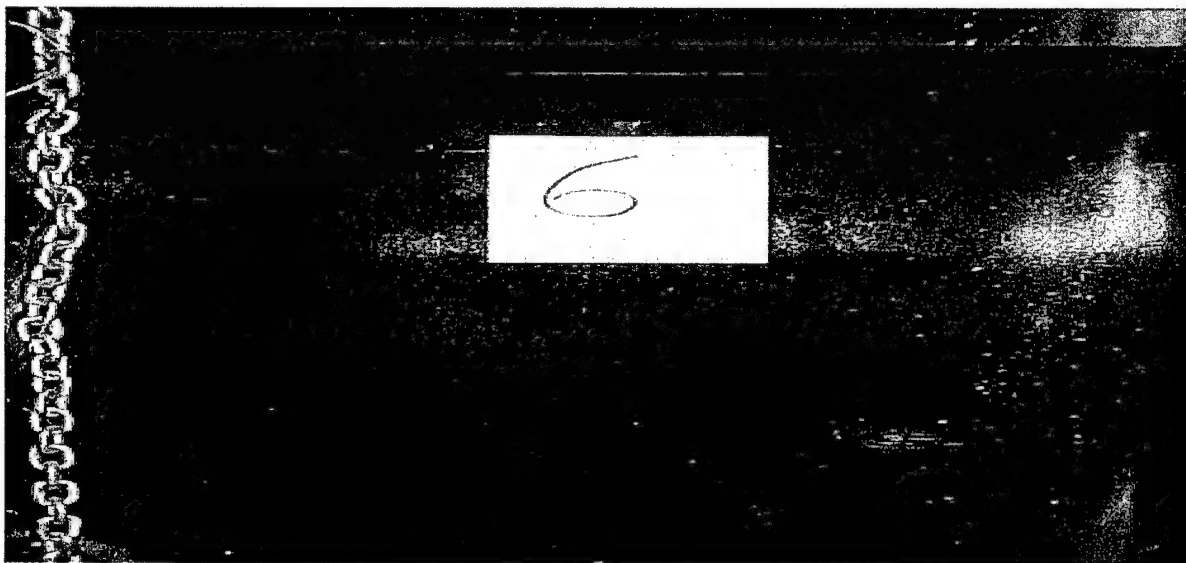
Figure 37. Heat Flux Profile, Pane #6

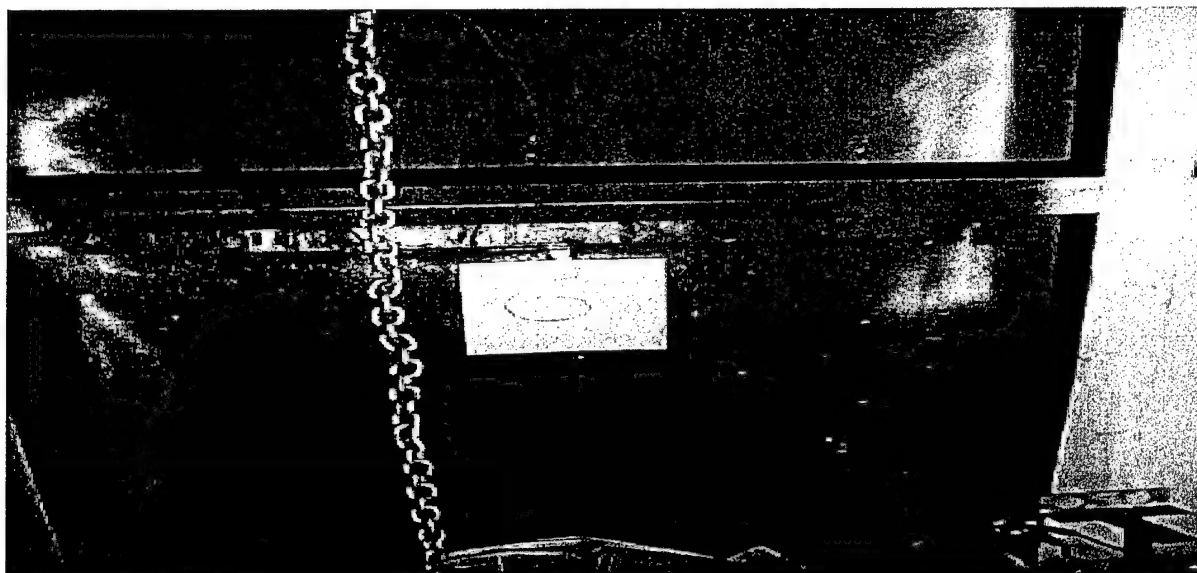**Figure 38. Untreated Forward Surface, Panel #6, Pre-Test**

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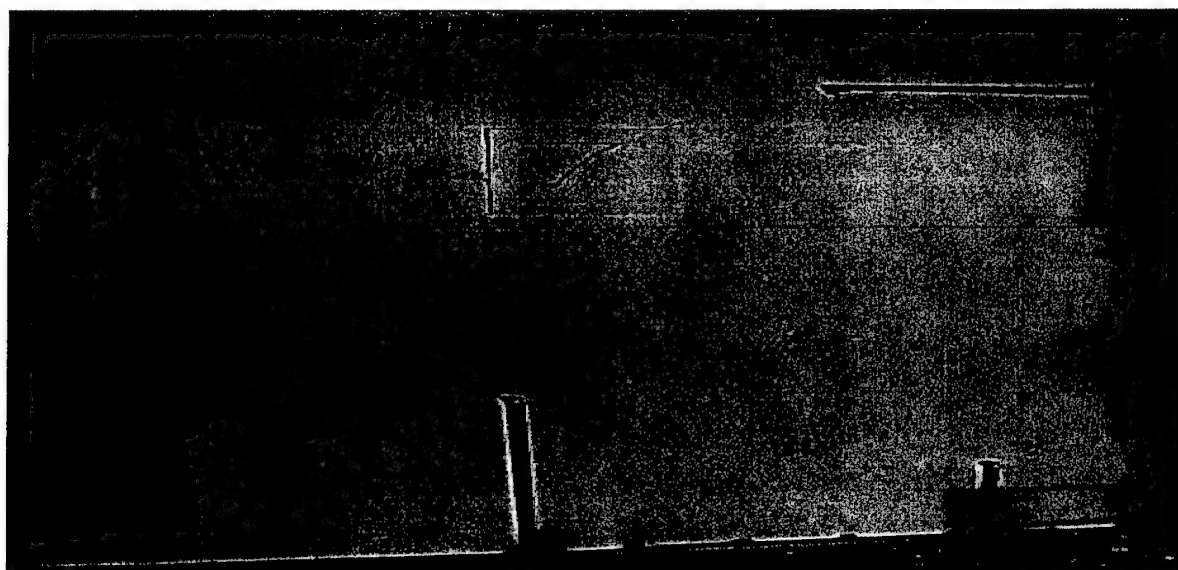**Figure 39. Untreated Forward Surface, Panel #6, Post-Test**

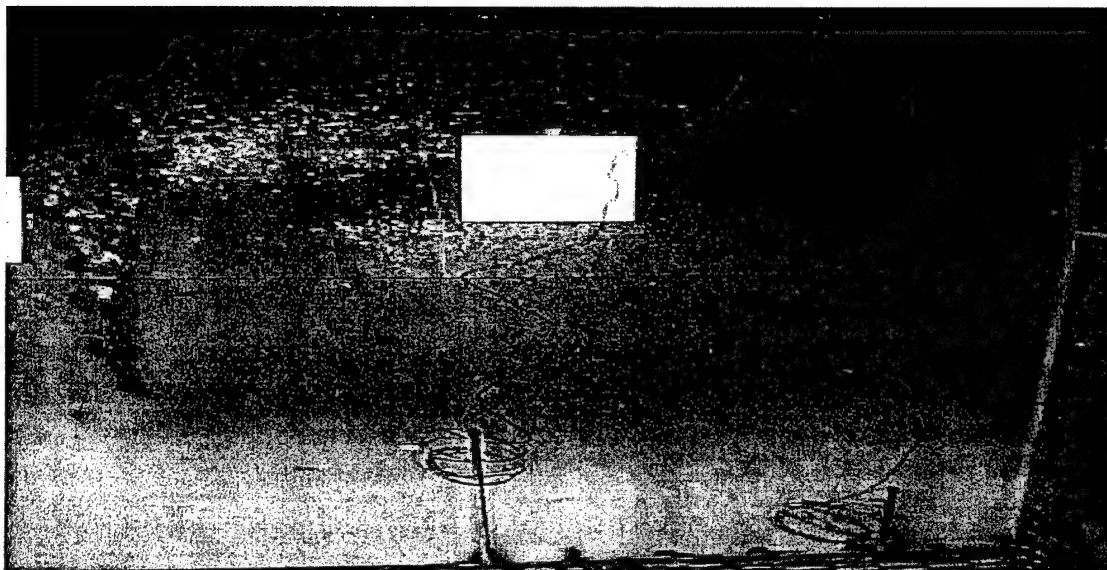**Figure 40. Fire Barrier-2, Pre-Test, Panel #7**

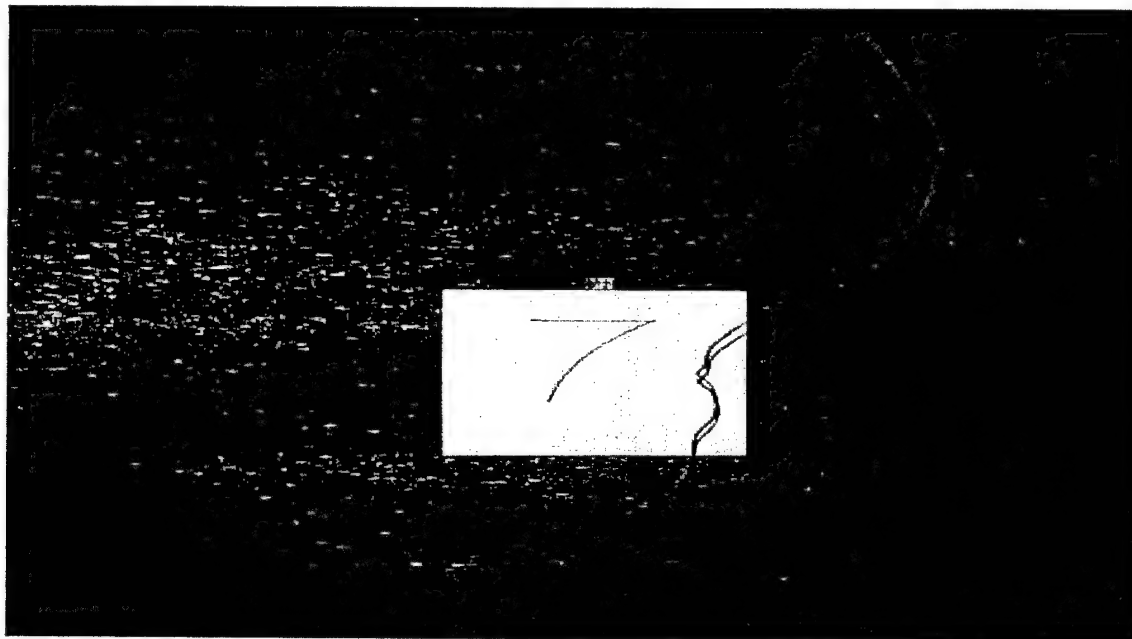Figure 41. Fire Barrier-2, Post-Test Panel #7

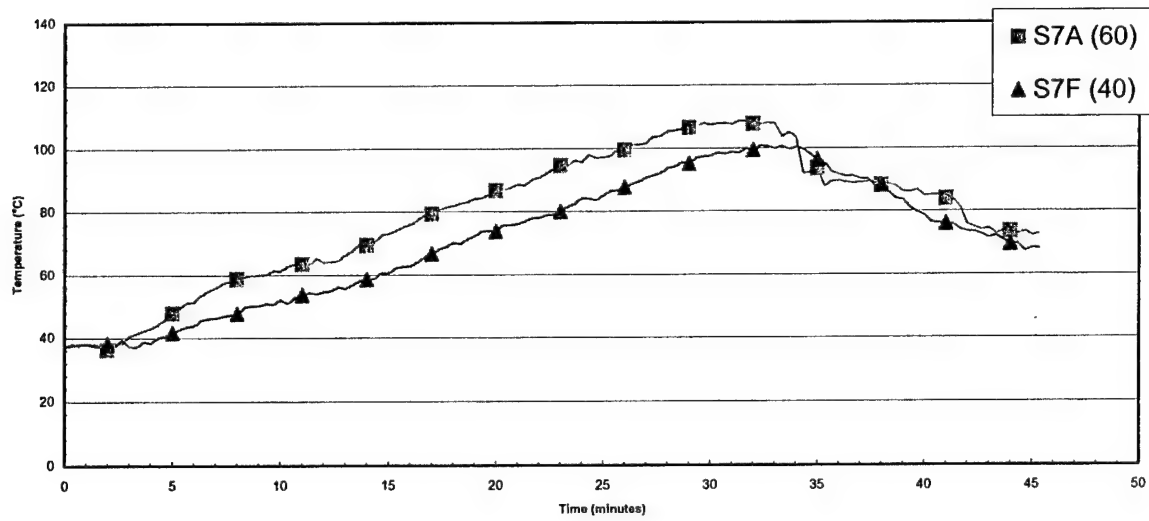Figure 42. Fire Barrier-2, Post-Test, Panel #7

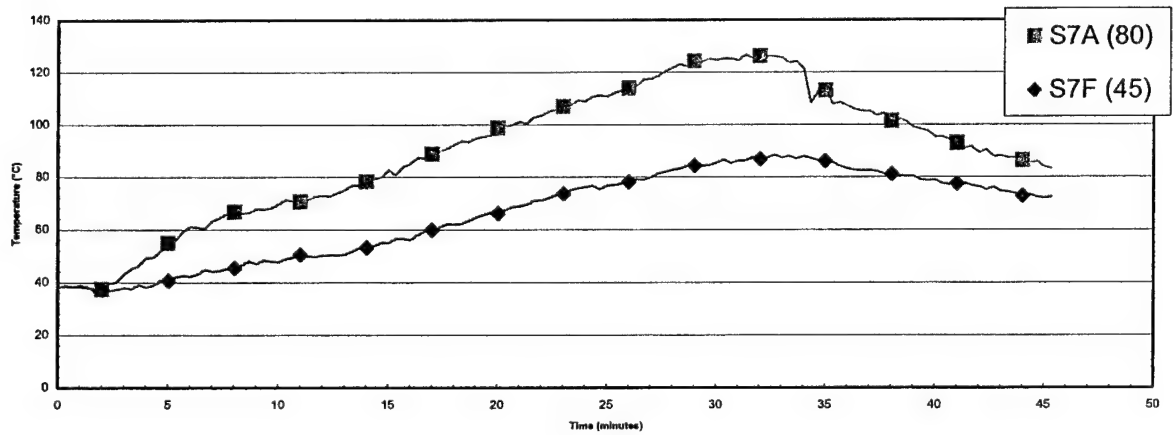**Figure 43. Temperature Profile, Panel #7, 16" Above Deck 60 Mil Fire Barrier 2-Vs. 45 Mil Temperature Coat**

Figure 44. Temperature Profile, Pane #7, 27" Above Deck 80 Mil Fire Barrier-2 Vs. 45 Mil Temperature Coat
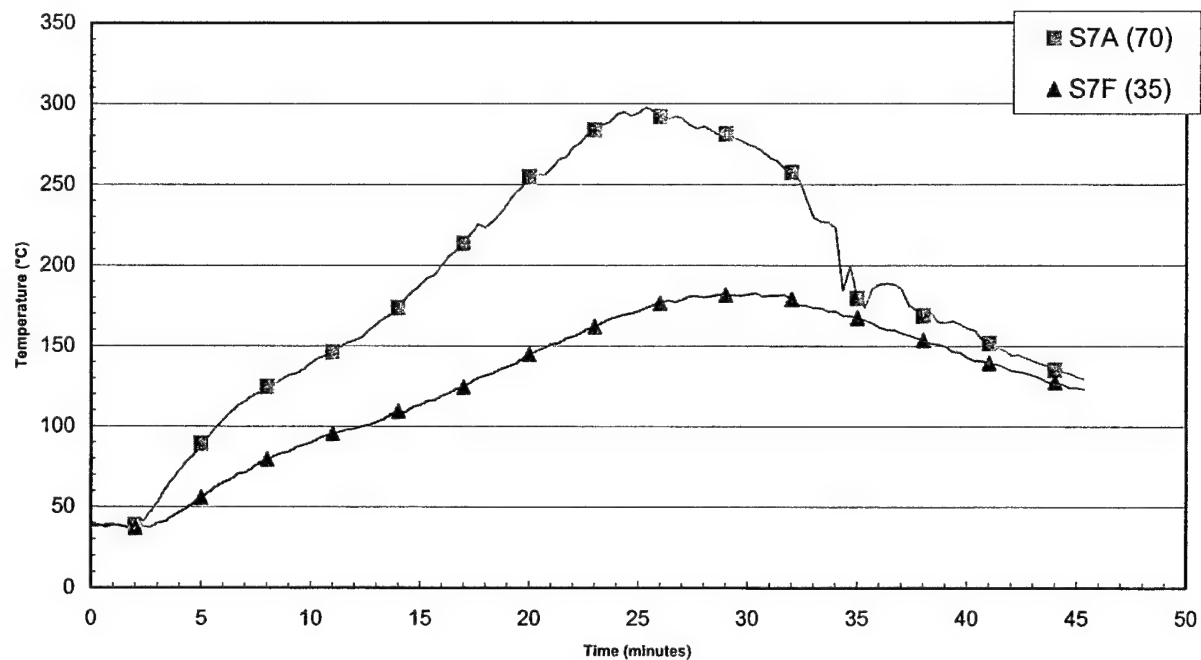
Figure 45. Temperature Profile, Panel #7, 66" Above Deck 70 Mil Fire Barrier-2, Vs. 35 Mil Temperature Coat
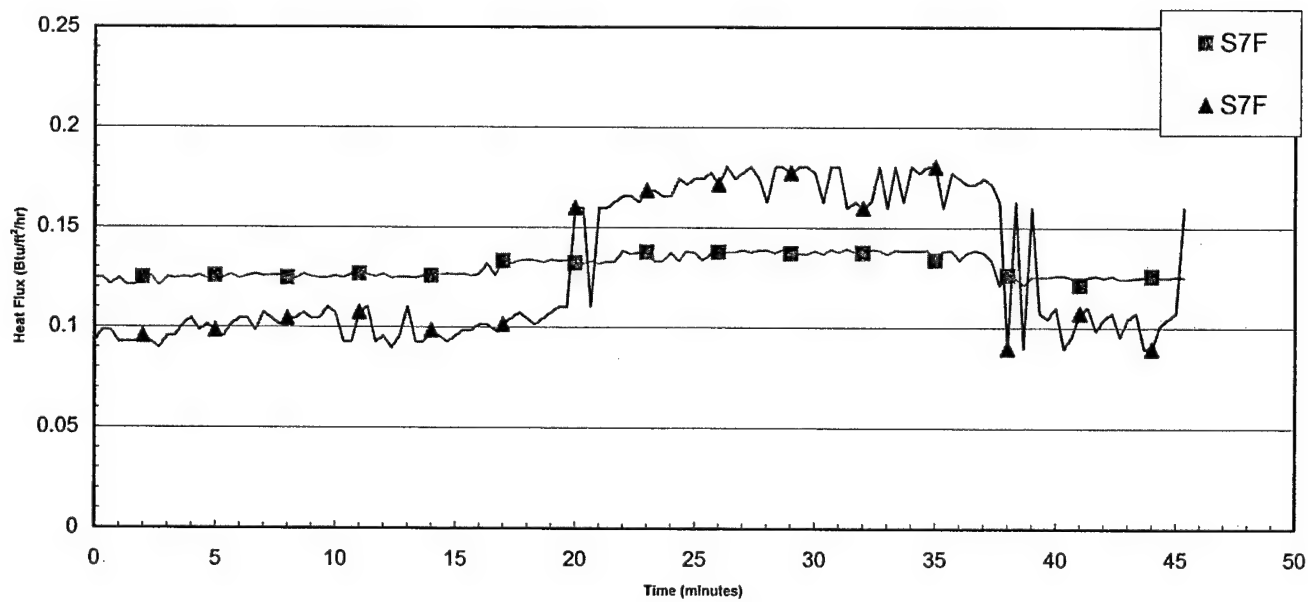

Figure 46. Heat Flux Profile, Panel #7

Figure 45, measured at 66" above the deck, shows the fireside thermocouple temperature rise being 10.9 °C/min (19.6 °F/min) while the forward side rise is 6 °C/min (10.8 °F/min). The temperature differentials were 33 °C (91 °F) at 5 minutes, 75 °C(167 °F) at 15 minutes and 126 °C (259 °F) at 24 minutes.

Figure 46 displays traces of radiant and total heat flux measured from the forward surface of the panel. The area of the panel these instruments were aimed at coincide with the thermocouple trace in Figure 44. The radiant flux trace resembles a step function with a clear, discrete increase at approximately 18 minutes and a slightly greater decrease at approximately 37 minutes.

The total heat flux trace exhibits a significant jump at approximately 21-22 minutes. This corresponds, in time, with the other increases in total flux seen in the previous panels. As has already been shown, this indicates an increase in free convection due to differences in heating rates of the steel surfaces in the compartment.

The thickness of application for all products evaluated was between 45 and 110 mils per surface. No controlled, quantitative evaluation of any Navy stock paint has ever been performed at this coating thickness. In general, surfaces aboard ship will receive 4 coats of paint during new ship construction or repair work. The average thickness of these four coatings is on the order of 10 mils per surface. Test data collected at the Advanced Fire Research Laboratory has shown that a combined 20 mil thickness of Navy stock paints, 10 mil per surface, will be insufficient to impede conductive heat transfer. The data represents the thermal insult due to a 1.5 MW wood crib fire (Figure 47) and a 2 MW hydrocarbon spray fire (Figure 48). These same 10 mil thickness of Navy stock paint have been shown to be incapable of withstanding the thermal insult from either of these fires without totally ablating (Figure 49). However, it's both misleading and inaccurate to compare the performance of a combined 20 mils thickness of one combination of paints with a 100 mil thickness of another combination of paints. Without data at the thickness currently being reported, there will be no way to predict how a Navy stock paint will affect conductive heat transfer to a boundary compartment.

5. Conclusions:

➤ The subject test coatings were applied in a range of thickness in excess of Navy paint application. Without further data, it would be difficult to assess the impact of these coating thickness on their observed performance.

➤ Radiant flux from the wood crib fire was insufficient to trigger any intumescent response in the C. B. Environmental products FB-1 and FB-520.

➤ Direct flame impingement from the heptane pool fire did not provide an insult sufficient to activate any large-scale, intumescent response from the C.B. Environmental product FB-2.

➤ The C.B. Environmental coatings FB-1, FB-2 and FB-520 may provide some thermal resistance to conductive heat transfer at an application thickness of 60 to 80 mils. However, without further supporting data, no definitive conclusion can be reached at this time.
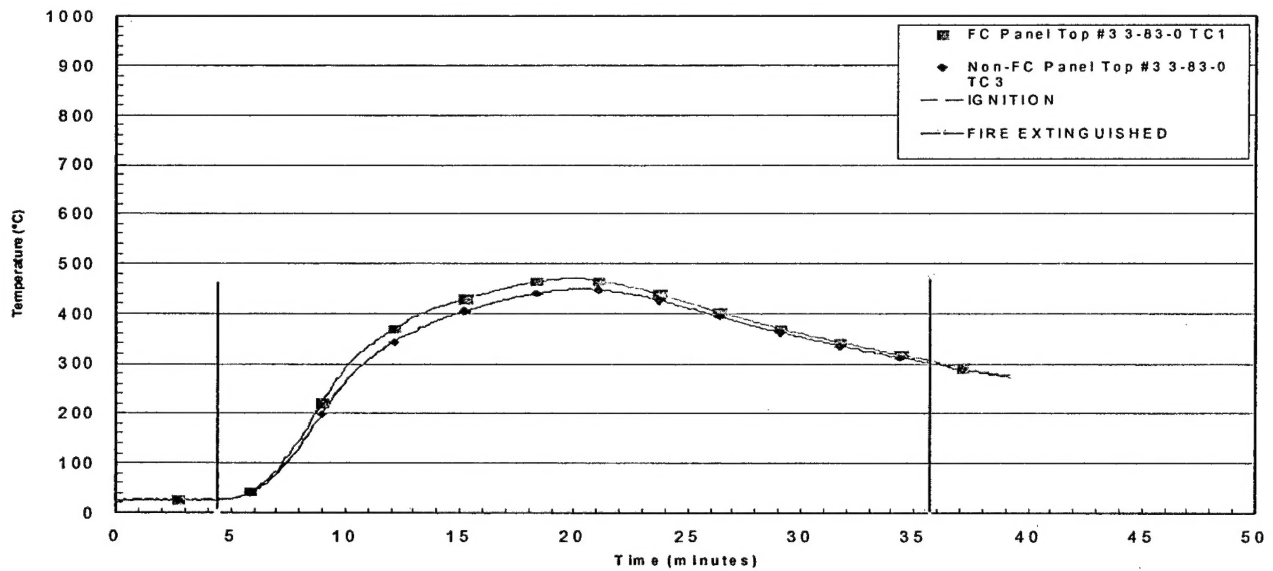
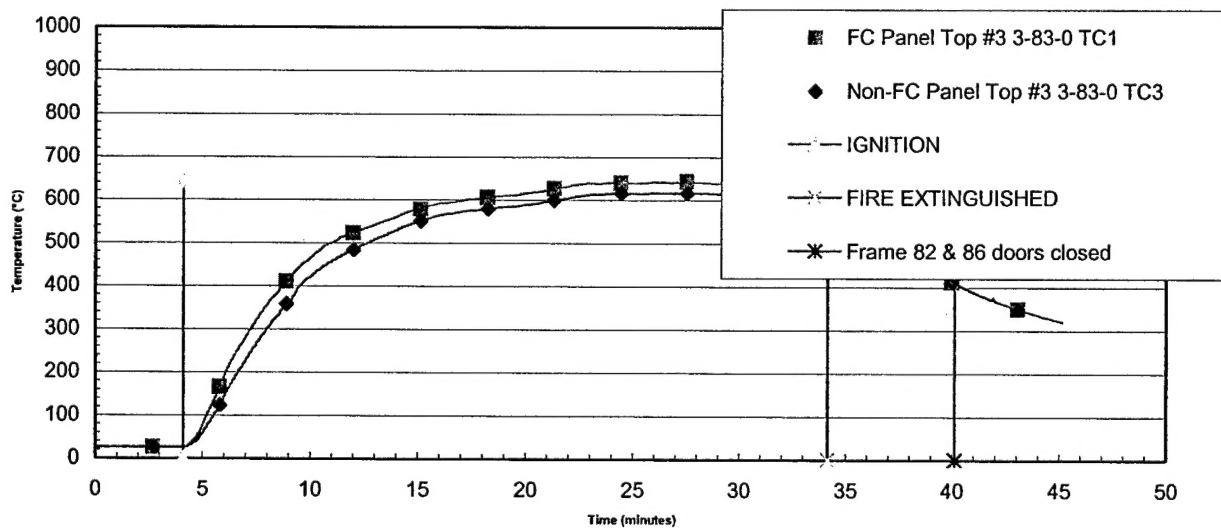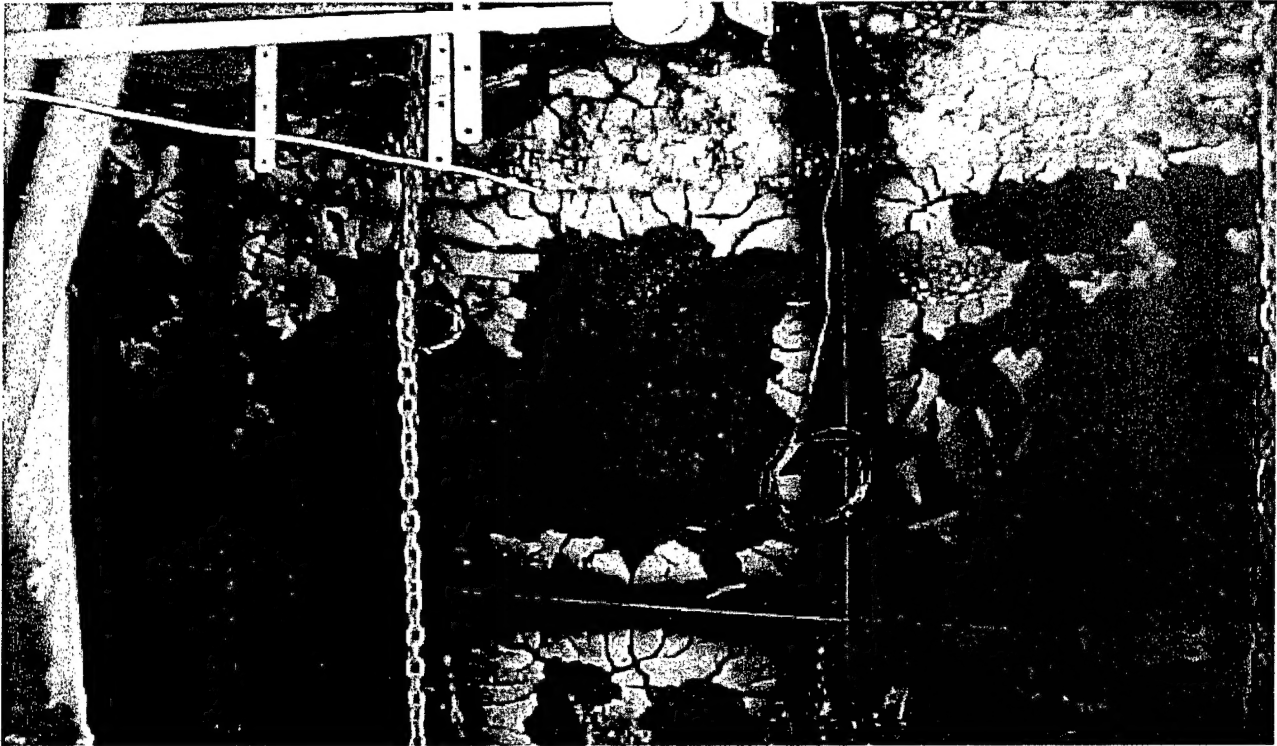**Figure 47. Temperature Profile, Navy Stock Paints 10 Mil Per Side, Combination F-150/F-124 1. 5 MW Wood Crib Fire**

Figure 48. Temperature Profile, Navy Stock Paints 10 Mil Per Side, Combination F-150/F-124 2 MW Heptane Spray Fire

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**Figure 49. Condition, Navy Stock Paints Exposed
To 1.5 MWWood Crib Fire**

➢ No correlation in heat transfer characteristics or overall performance can be drawn between the subject test paints and any Navy stock paint without additional data on Navy paints at the reported thickness.

➢ Without further data and more clearly defined performance trends, no definitive conclusions can be reached on the usefulness of any of the subject coatings in a Naval shipboard environment.

8. <u>Recommendation</u>:

The Naval Sea Systems Command should withhold any decision on implementing use of the subject coatings until further data and performance trends can be acquired.

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